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TECHNICAL REPORT

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THE D.R.C.S. ACOUSTIC SOUNDING FACILITY AT EDINBURGH AIRFIELD

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S U M M A R Y

The DRCS acoustic sounding facility at Edinburgh Airfield has been developed to enable the simultaneous comparison of the ability of three acoustic sounding techniques to measure wind velocity profiles in the lower atmosphere. The three techniques are monostatic doppler, bistatic doppler and angle-of-arrival operation. The antenna configuration, electronic equipment and performance parameters are described.

Approved for public release

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1. INTRODUCTION

This report is a description of the equipment being used by Tropospheric Studies Group at the Defence Research Centre Salisbury, to determine the suitability of an acoustic sounding system for measuring wind profiles in the lower 300 m of the earth's atmosphere in the vicinity of airports. The interest in this remote sensing technique stems from a desire to improve airport safety by giving advance warnings to aircraft pilots of dangerous wind shear conditions during landing approaches.

2. TASK OBJECTIVES

The task has two main objectives:

(a) to examine the advantages and disadvantages of three forms of acoustic sounding. These are:

- (i) monostatic (one antenna) operation, where wind information is derived from doppler information contained in the returns;
- (ii) bistatic (two or more antennas) operation, which also relies on doppler information; and
- (iii) angle-of-arrival operation, which relies on obtaining wind information from the angle at which a reflected wavefront enters the receiving system antenna; and

(b) to gather data 24 hours per day over a period of 12 months. From these data, statistics will be generated showing how the various sounding techniques perform during different seasons of the year and how their performances vary from day to night. The statistics will also show the height ranges over which useful data can be obtained under these varying conditions.

Other minor objectives of the task are to examine the effect on performance of various noise sources such as wind induced noise, vehicles and aircraft, and rain falling on the antenna. The effectiveness of screening the antenna from noise sources is also to be assessed.

3. ACOUSTIC SOUNDING

The acoustic sounder is a ground based remote sensor which exploits the relatively strong interaction between acoustic waves and small scale variations in air temperature and velocity, created within turbulent regions of the lower atmosphere(ref.1). In practice, short pulses of acoustic energy are transmitted upwards into the atmosphere at intervals of two to eight seconds, depending on the required height range, from highly directional acoustic antennas on the ground. As the pulses travel through turbulent regions, a small fraction of their energy is scattered back towards the ground. Some of this scattered energy is subsequently collected by one or more acoustic antennas, amplified and then processed to extract information. From this information, facsimile records can be produced showing the height and intensity of scattering regions in the lower atmosphere as a function of the time of day, while doppler shifts provide data on the movement of air, both vertically (as in thermal plume activity) and horizontally. The angle at which the scattered energy enters a suitably designed antenna can also, theoretically, give information on wind velocity.

4. MONOSTATIC AND BISTATIC OPERATION

Monostatic and bistatic modes of operation are shown in figures 1 and 2. Monostatic operation takes place when the same antenna is used for both transmitting and receiving functions. Bistatic operation occurs when a separate antenna (or antennas) is used to receive the scattered returns. The two techniques are employed because of the nature of the scattering processes for acoustic waves in the lower atmosphere. Theoretical investigations predict that, if temperature gradients are absent, scattered acoustic energy can be received from air velocity inhomogeneities using a bistatic configuration, but not when using a monostatic configuration. This is due to a null in the scattering pattern. In general, when using the bistatic configuration, strong acoustic returns are only obtained from the common volume, ie, the region where the transmitting and receiving antennas field patterns intersect. Typical monostatic and bistatic facsimile records covering the same time interval are shown in figure 3.

5. ANGLE-OF-ARRIVAL

At the time the task was initiated, development work on the angle-of-arrival technique was in progress following a number of years' work on monostatic and bistatic doppler configurations. This work was carried on during the early stages of the task but it soon became apparent that the technique was not going to be a success, due to the inadequacies of the antenna and a lack of understanding of the true nature of the complex reflected wave fronts entering the antenna. Consequently, the great majority of statistical data gathered is confined to the doppler systems. A brief description of the angle-of-arrival system will be given for the sake of completeness and also because it influenced the configuration of the acoustic transducers in the transmitting and receiving antennas, and the transmitter power amplifiers.

6. EQUIPMENT REQUIREMENTS

In order to carry out the objectives of the task, it was considered necessary to put into the one installation sufficient equipment to enable, if required, simultaneous operation of all three modes of acoustic sounding without any mutual interference. This was essential if comparative performances under identical weather conditions were to be established.

The installation was set up at the Edinburgh air force base, 480 m from the main runway and remote from the hangars and workshops. Figure 4 shows the layout of the installation. Five antennas, consisting of transducers set in parabolic reflecting dishes 2 m in diameter, are laid out as shown. Four are positioned at the corners of a square and the fifth, pointing vertically upwards, is set in the middle. The four outer dishes are inclined 30° off the vertical and are directed to a common volume 160 m above the centre dish. The diagonals of the square point North-South and East-West respectively. Theoretically, only three outer antennas are required to resolve the doppler data to give wind direction; however, the set of four provides increased versatility and a choice of direction when transmitting from an inclined antenna. Shielded cables connect the acoustic transducers in each dish with the electronic equipment which is housed in a nearby van. An anemometer and temperature and pressure transducers, positioned at a height of 10 m, provide a direct measure of low level atmospheric conditions.

Using the antenna configuration described, the following monostatic and

bistatic modes of operation are possible:

(a) vertical monostatic operation, when the centre antenna transmits and then receives scattered energy;

(b) inclined monostatic operation, when any of the outer antennas transmits and then receives scattered energy;

(c) bistatic operation, when the outer antennas receive scattered energy transmitted from the centre antenna; and

(d) bistatic operation, when the centre antenna receives scattered energy due to transmissions from any of the outer antennas.

By choosing an appropriate transmitting sequence it is possible to operate the equipment in monostatic, bistatic and angle-of-arrival modes virtually simultaneously and without mutual interference. The sequence which is most commonly employed lasts for eight seconds before repeating. It begins with a transmission from the centre antenna (at 2500 Hz and usually of 50 ms duration), followed after 2 s by a transmission from either the North or the South antenna. After 2 s, the centre antenna again transmits, followed in another 2 s by either the East or West antenna. Other transmitting sequences are possible and are described in more detail later in the report. After each transmission, all antennas are switched to the receive mode. During the following interval, parameters such as received signal strength, doppler shift, data quality, etc, from all antennas, as well as the meteorological data, are fed into the input of a 32-channel multiplexer. Using a microcomputer, based on the Intel 8008 microprocessor, the data are sampled and stored every 50 ms. By averaging pairs of data samples, the height range of 300 m (assuming a 2 s transmission interval) is divided into 20 height levels. The data appropriate to each height are stored and averaged over a 2 min interval, taking into account the quality of the data. Every 8.5 min, the data are punched out on paper tape for later analysis using an IBM 370 computer. During each punching sequence, selected doppler profiles are drawn on an XY plotter under the control of the microcomputer. Range gated integrators enable selected bistatic or monostatic data, appropriate to a particular height interval, to be displayed on multi-channel pen recorders for real time data monitoring. Figures 5 to 10 are photographs of the electronic equipment inside the van and external views of an antenna, an acoustic transducer assembly and an antenna screen.

7. DOPPLER CONFIGURATION

Figure 11 shows the basic components of the acoustic sounder electronics and the doppler recording and processing facility. As far as the equipment is concerned, there is no difference between monostatic and bistatic operation apart from ensuring that the data are collected from the appropriate antennas for display on facsimile records and on the chart recorders. The antennas must also be correctly identified by the microcomputer while processing input data.

The components shown inside the dotted line are repeated five times, once for each antenna. The electrical output from the transducers in each antenna is brought to the equipment van by means of shielded cables. These cables terminate at a transmit/receive changeover relay unit which controls the function of the antenna. In the receive mode, incoming signals are passed through a 53 dB gain pre-amplifier, followed by a bandpass amplifier to minimise unwanted noise. The amplifier has a pass band of 260 Hz centred on 2500 Hz with rapid attenuation increase outside this band (figure 23). It also provides an additional gain of 40 dB. One output from the amplifier goes to a logarithmic

amplifier and detector which gives an output proportional to the logarithmic power of the input signal. A second output from the bandpass amplifier is further amplified and then hard limited before being passed on to a phase-locked loop tracking filter whose loop bandwidth is 44 Hz. The relatively large loop bandwidth is necessary to allow for fast signal acquisition and the high slew rate necessary to follow rapidly changing doppler shifts associated with large wind shear conditions. The tracking filter produces an output which is directly proportional to the doppler shift in the acoustic returns. An additional output, called a 'Lock Indicator', provides information on the quality of the data being received and is used by the microcomputer to accept or reject the incoming data.

Two transmitters are used to drive the antennas. One feeds the outer antennas while the other is used exclusively on the centre one, this division being necessary for one aspect of angle-of-arrival operation.

The five sets of doppler, lock indicator and signal strength data are fed into the input of a 32-channel multiplexer along with the anemometer wind speed and direction information, temperature and air pressure data. Other channels provide for angle-of-arrival data and include spares for future requirements. All channels are sampled once every 50 ms, passed through an analogue to digital converter and then into the microcomputer. The microcomputer stores and averages the data applicable to 20 height intervals and periodically outputs the processed data via the paper tape punch and the XY plotter.

A number of range-gated integrators allow selected doppler information, relative to a specified height interval, to be displayed continuously on a chart recorder for real time monitoring. Monostatic or bistatic doppler information from any antenna can be chosen for any specified height interval. Sampling intervals are set by a range-gate which enables up to four independent time intervals to be selected simultaneously.

In order to provide height versus time facsimile records of the intensity of the acoustic returns and hence the structure patterns of the lower atmosphere, a number of Muirhead facsimile (Mufax) recorders are employed. These derive their inputs from 'write amplifiers' which in turn obtain their inputs from up to three amplitude receivers connected to selected antennas at the appropriate (nonlimiting) bandpass amplifier outputs. The receivers have two automatic gain control functions, one compensating for the overall level of the input signal and the other compensating for the decrease in signal strength with height of return. The facsimile recorder can be set to a 2-, 4- or 8-s sweep. The write amplifiers are provided with four multiplexed inputs. The combined facilities enable 1, 2 or 4 separate facsimile pictures to be produced on the one record. They can be from separate antennas or monostatic and bistatic records from the one antenna, enabling simultaneous visual comparison of the two modes of operation (figure 3).

In an installation such as this, which enables simultaneous operation in several different modes, timing is vital. The heart of the installation is the sequence generator and timing unit which generates the selected transmitting sequences, operates the transmit/receive changeover relay units, and controls the transmit pulse length, repetition rate and modulation envelope (slow rise and fall times are necessary to extend the life of the antenna transducers). It provides sense lines to the microcomputer to supply information on system status and provides signals to synchronise the facsimile recorders, to control the write amplifier input multiplexer and to control the height A.G.C. function in the amplitude receivers. The unit provides a clock frequency for the range-gate and generates inhibiting signals to ensure that the range-gated integrators sample only during a selected portion of a transmitting sequence. It also contains a clock which generates a time code which is punched onto the facsimile records every hour along with a machine number identification code and range gate position markers.

In key areas, light emitting diodes (LED) provide visual displays to the operators of timing and system status. These show the transmit sequence and indicate when range-gated integrators are inhibited and when sampling occurs. They also show which of the four multiplexed inputs of the facsimile write amplifiers are connected through at any instant. These displays are essential to enable the operators to set up new recording configurations quickly.

8. ANGLE-OF-ARRIVAL CONFIGURATION

Figure 12 shows the basic components of the discontinued angle-of-arrival system. The system is based on the monopulse radar concept, which makes use of the fact that the returns entering the antenna at an angle to the main axis do not pass through the focal point of the parabolic dish upon reflection but are offset to one side. When a cluster of four transducers are arranged in a square pattern in the focal plane and surrounding the focal point, the relative amplitudes received by the four transducers should give an indication of the angle at which the incoming acoustic wave front enters the antenna. Conversely, if the drive levels are varied prior to transmission then it is possible to steer the beam several degrees off the main axis.

As explained earlier, all the antennas, relay units and transmitters used on this project are based on the angle-of-arrival concept. Each antenna contains a group of four transducers surrounding the focal point and these are connected by four separate shielded cables to the electronic equipment housed in the van. Each transmit/receiver changeover relay unit handles four lines and each transmitter has four outputs, the levels of which, if required can be varied with respect to each other. For angle-of-arrival operation, the four outputs of the appropriate relay unit are fed into the input of an elaborate pre-amplifier shown in block diagram form in figure 20. This pre-amplifier takes the inputs, sums and differences them in various combinations, introduces 90^{o} phase shifts to some of the resultants and then forms vector additions. The result is four new outputs. The phase shift between one pair gives an indication of the resolved angle-of-arrival in say the North-South direction, while the phase shift between the second pair gives an indication of the resolved angle in the East-West direction.

As in the doppler systems, each of the four pre-amplifier outputs are passed through standard bandpass amplifiers to reduce noise, hard limited and then fed to phase-locked loop tracking filters to reduce noise further. While doppler information can be obtained from the VCO control voltage of any of the tracking filters, the a.c. outputs of the VCOs of each appropriate pair of tracking filters are fed to phase detectors. These produce output voltages giving an indication of the two resolved angles-of-arrival of the acoustic wave front.

In one angle-of-arrival configuration, the aim is to steer the transmitted beam into the wind at such an angle that the acoustic returns, appropriate to a particular height interval, enter the antenna with an angle-of-arrival offset of zero degrees. To accomplish this, the two previously mentioned phase detector outputs are sampled by range-gated integrators to provide error voltages for a closed loop system controlling the drive levels of the four outputs of the transmitter. The error voltages are amplified and then fed into a circuit which resolves the two inputs into four outputs to control the transmitter drive levels (figure 14).

During simultaneous monostatic and bistatic doppler operation, angle-of-arrival information can also be fed into the multiplexer and microcomputer for recording and later analysis.

9. EQUIPMENT CONSTRUCTION

Figure 6 is a picture of the main portion of the acoustic sounder electronics. The lefthand rack contains the two transmitters and their power supplies. The next rack contains (starting from the top) the transmit/receive relay units, an outlet for timing signals, pre-amplifiers, bandpass amplifiers, logarithmic amplifiers, amplitude receivers, tracking filters, range-gated integrators and rage-gate generator. The next rack contains the sequence generator and timing unit, the microcomputer, the 32-input multiplexer and the meteorological data electronics. The fourth rack contains test equipment and a Muirhead facsimile recorder. A fifth rack contains a second facsimile recorder and the write amplifiers. Shelves support chart recorders, the XY plotter and the paper tape punch.

Many of the electronic circuits are built on circuit cards which plug into card bays. Generally only the power supplies are fed to the cards via the multi-pin connectors at the rear. Most of the inputs and outputs are brought out to miniature coaxial sockets mounted on individual front panels attached to each circuit card. Interconnection between units is made via plug-in coaxial cables. The versatility of this system allows for easy maintenance, modifications and rapid changes in system configuration when required.

10. OTHER FACILITIES

Other facilities are available, such as a four-channel magnetic tape recorder which is used for recording acoustic returns for later spectral analysis. It is also used for recording analogue data via voltage-to-frequency converters.

The transmitter signal source is provided with a frequency control input which, under microprocessor control, allows for experiments in chirp and coded frequency hop transmissions.

11. ANTENNAS

Each of the five antennas consists of a fibreglass parabolic reflector having an aperture diameter of 1.905 m (75 inches) and a focal length of 0.597 m (23.5 inches). The four outer antennas are fitted with stands which tilt them 30° off the vertical. The acoustic transducer, which is positioned in the centre of the focal plane, is a square cluster of four Philips 1 inch dome tweeters, type AD0160/T8. Each tweeter is acoustically matched to the air by a square cross-section, exponentially tapered horn, constructed from brass plate. The horns are 37.66 cm (14.83 inches) long, the throat 0.63 cm x 0.63 cm (0.25 inch x 0.25 inch) and the open end 6.85 cm x 6.85 cm (2.7 inch x 2.7 inch). Externally they are coated with an acoustic damping compound to minimise ringing effects. The open ends of the horns lie in the focal plane of the parabolic reflector. Figures 9 and 10 show pictures of the completed antenna and transducer arrangement.

The electrical impedance of each tweeter is 8 Ω. The normal input drive level is 25 W per unit, making a combined input of 100 W. It is estimated that the overall efficiency of the transducer system is about 15 per cent giving an acoustic output of 15 W per antenna.

The half-power beamwidth of each antenna, at 2500 Hz, is 5.5°. This was determined by computation taking into account the transducer configuration. An attempt was made to measure the actual field pattern. The antenna axis, however, had to be tilted horizontally as a result of which, ground reflections,

and also wind and atmospheric turbulence, produced highly variable results on consecutive sets of field pattern measurements. The results, nevertheless, supported the theoretical determination.

The transducers were originally covered by a fibreglass housing for weather proofing purposes. However, it was discovered that the enclosed chamber reverberated following each transmitter pulse. The reverberation time varied from 50 to 300 ms and the reverberation frequency was not necessarily the same as the original transmitted frequency, but could at times differ by as much as 70 Hz. The difference varied with the ambient temperature. Following this discovery the covers were either left off or replaced by ones made from an acoustic damping material consisting of foam plastic lined with lead sheet.

12. ANTENNA SCREENS

In order to reduce ambient noise levels and wind noise, each antenna is surrounded by a screen 2.44 m (8 feet) high as shown in figure 8. In plan view the centre screen is 2.44 m square while the outer screens are 3.05 x 2.44 m (10 x 8 feet) and only 1.83 m (6 feet) high at the end towards which the antenna is inclined. They consist of 1.27 cm (0.5 inch) plywood panels supported by a rigid framework. The inside walls are lined with 5 cm thick fibreglass insulation which is held in place by bagging. The inside lining reduces the internal reflection of sound which is diffracted over the top edges of the screen. The screens reduce the ambient noise levels by 15 to 20 dB. They also have another important effect. Spectral analysis of ambient noise from an unshielded antenna, measured at the bandpass amplifier output, showed a heavy bias towards the low frequency end of the filter response. Screening the antenna removed this bias. It was concluded that the variation of the antenna field pattern with frequency, at angles 90^o off the main axis, was responsible for the bias. Figure 13 shows spectral plots of noise from one antenna before and after shielding.

13. TRANSMITTERS

Two transmitters are used to pulse the antennas. As explained earlier they were originally developed for angle-of-arrival experimentation. Both units are identical and have the capability of steering the transmitted beam up to 2.7^o away from the antenna axis. In the current task it was intended that only the centre antenna should be subject to angle-of-arrival operation, hence one transmitter was coupled to the centre antenna while the other was coupled to the four outer antennas and remained permanently in a non-steering mode.

Figure 14 shows the basic circuit components of the transmitters. Each one has four identical output stages. The input to each stage is split, with one signal passing through an inverting buffer, to produce two antiphase signals. These are then fed to two SI-105A power amplifier modules, which drive one transducer in a push-pull arrangement. The normal input drive level to each transducer is 25 W. A combined power of 100 W is therefore delivered to each cluster of four per antenna. This drive level is sustained for 50 to 150 ms, depending on the selected pulse width. During each transmission, each stage is connected to the 2500 Hz signal source by means of a field effect transistor (FET) switch.

In order to achieve beam steering, the four input drive levels must be varied relative to each other. This is accomplished in the manner shown in figure 14. Two d.c. inputs, X and Y, provide for resolved deflections in the East-West direction and the North-South direction. The two inputs are fed into a summing and differencing circuit which produces four outputs having the relative outputs:

$-(X - Y)$

$+(X + Y)$

$+(X - Y)$

$-(X + Y)$

These outputs are then used to amplitude modulate the 2500 Hz signal source by means of a quad multiplier. The four outputs are then:

$A = E(1 - (X - Y)) \cos 2\pi ft$

$B = E(1 + (X + Y)) \cos 2\pi ft$ where $0 < X < 1$

$C = E(1 + (X - Y)) \cos 2\pi ft$ $\quad 0 < Y < 1$

$D = E(1 - (X + Y)) \cos 2\pi ft$ $\quad f = 2500$ Hz

E is the amplitude of the unmodulated 2500 Hz signal

The relative positions of the A, B, C and D transducers in each antenna are shown in figure 21. Removing the X and Y signals automatically grounds the inputs and allows for normal operation. Figure 15 shows a succession of computer generated field patterns, ranging $\pm 20^{\circ}$ about the main axis, showing how the main lobe deflects as X is varied from 0 to 1 in 20 successive steps, keeping Y = 0.

Early operation of the transmitters led to a high transducer failure rate. The cause was attributed to the use of the FET switch used to connect the signal source to the power amplifiers. The input voltage at the instant of connection can be anywhere between zero and the peak of the sinusoidal input. In the vicinity of the peak, the nearly instantaneous rise in signal amplitude imposes severe strain on the transducers. In order to overcome the problem a fifth multiplier was placed in the output of the signal source. A d.c. pulse with a predetermined rise and fall time is fed into the modulation input. The resulting output is a burst of 2500 Hz with the same modulation envelope shape as the d.c. pulse. The pulse shape is generated in a programmed Read-Only Memory (ROM) by the sequence generator and timing unit. The pulse shaping has resulted in a considerable extension of transducer life.

14. 2500 HZ SIGNAL SOURCE

The 2500 Hz transmitting frequency is supplied by an oscillator based on a voltage controlled oscillator integrated circuit, type ICL 8038 AC. The circuit is shown in figure 16. It provides both sinusoidal and square wave outputs and metering to monitor the level of the selected output. The sinusoidal output is used to drive the transmitters. The frequency is set by means of a panel mounted potentiometer. In order to maximise frequency stability, the oscillator is fed by subregulated voltage supplies. A switch allows the frequency to be controlled by an external input voltage. An input range of ± 2.5 V shifts the frequency by ± 500 Hz. This facility allows for testing of the tracking filters and experiments in chirp and coded frequency hop transmissions.

15. TRANSMIT/RECEIVE CHANGEOVER SWITCH

The transmit/receive changeover switches are based on electromagnetic relays. The circuit of a typical unit connected to one of the antennas is shown in figure 17. Each unit switches both conductors of the four sets of balanced line feeding the antenna. 12 relays, each containing two sets of changeover contacts,

are required. They are split up into three groups. During a normal transmit sequence the timing of the operation of the three sets are shown in figure 18. Prior to transmission the antenna is connected through to the receiving system. At the commencement of the transmit sequence, relay D operates and short circuits the receiving system input to minimise receiver response during transmission. 20 ms later, relay C operates and switches the antenna from the receiving system to the transmitter feeder, which is still open due to relay B. After a further 20 ms relay B operates to complete the circuit to the transmitter. A short time later, depending on the selected pulse width, the transmitter receives (via a FET switch) an input signal which it amplifies and delivers to the antenna. 20 ms after the cessation of the signal, relay B is released and opens the transmitter line. After a further 20 ms, relay C releases and switches the antenna through to the receiving system. The release of relay D, which removes the short circuit on the receiver input and completes the receiving circuit, is controlled by the return to zero of two inputs to the relay driving circuit. One is input 4 (figure 18) and the other is the variable length input 5, generated by a monostable which is initiated upon the cessation of the relay C controlling input 3. This variable delay or blanking period is used to eliminate the effects of transducer ringing from the receiving system following a transmission. The control is set in the front panel of the sequence generator and timing unit.

16. PREAMPLIFIERS

Two types of preamplifier were used, each having similar input and output stages. The simpler of the two is used in doppler operation while the more complex one was used in angle-of-arrival investigations.

The doppler preamplifier (figure 19) consisted of a single input stage built around a low-noise amplifier (IC type μA739) arranged to have a gain of 40 dB. It is coupled to the antenna transducer by means of a miniature coupling transformer (nominally 12 Ω : 600 Ω). The amplifier inputs are protected by a pair of diodes against accidental overload conditions. The output is buffered by a μA741 operational amplifier with unity gain. The overall gain including the transformer coupling is 53 dB.

At the rear of the input connector, the four input lines from the antenna are connected in series to provide a single input to the preamplifier. A series-parallel connection giving a source impedance of eight Ω would have provided a better impedance match and a small improvement in sensitivity. However, the series arrangement had the advantage of giving a positive indication, by an absence of output, of a transducer failure. Metal fatigue in the diaphragm coils produced an overall failure rate of about one every four weeks.

The preamplifier developed for angle-of-arrival operation consisted of four input stages identical to the one in the doppler preamplifier. Each input was connected to one of the transducers in the antenna. The resulting outputs were then fed to a series of summing, differencing and phase shifting stages which produced a number of signals with varying phase relationships to each other. Each of the outputs was buffered by a μA741 operational amplifier with unity gain. It was hoped that a measurement of phase between selected outputs would give an indication of the angle-of-arrival. Figure 20 shows the various stages of the preamplifier signal processing in block diagram form. Figure 22 is a vector diagram showing the phase relationship between the outputs used in the attempted angle-of-arrival determination.

17. BANDPASS AMPLIFIERS

The preamplifiers are relatively wideband; they begin to roll off at about 16 kHz. In order to minimise the effects of unwanted noise, the preamplifier

outputs are passed through bandpass amplifiers. Each amplifier consists of two identical sections in cascade. Figure 23 shows the frequency response of one section and also of two combined. Each provides a gain of 20 dB, adding a further 40 dB to the system gain. The combined passband is 260 Hz centred on 2500 Hz with rapid attenuation outside this band. This bandwidth allows for a maximum doppler shift of ± 130 Hz which, in the bistatic mode, corresponds to a wind velocity of 35.6 m/s and, in the monostatic mode, to a wind velocity of 17.8 m/s. Each section consists of a set of three stagger-tuned active filters based on the state-variable type. The circuit is shown in figure 24, which also gives the bandwidths and centre frequencies of each active filter. In order to achieve a flat passband and closely matched phase caracteristics, the centre frequencies are adjusted to within 1 per cent. Silver mica capacitors and metal-film resistors are used in the frequency-determining elements, for improved temperature stability.

The output of the second filter section has several destinations; the amplitude receiver which produces facsimile pictures, the logarithmic amplifier which produces an output indicating signal strength, the doppler-tracking filters and finally a phase detector for angle-of-arrival operation. The latter two are supplied from a second output which has undergone an additional 40 dB of amplification with controlled limiting. The circuit of the limiter is included in figure 24.

18. AMPLITUDE RECEIVERS

Each amplitude receiver, shown in figure 25, produces an output suitable for feeding the facsimile recorder, via the 'write amplifier'. The recorder creates a height versus time record of the regions in the lower atmosphere which are scattering the transmitted acoustic energy. It receives it's input from a selected (nonlimiting) bandpass amplifier output. Because of the 60 dB dynamic range, from system noise to the onset of limiting, the filter output is unsuitable for feeding direct to the facsimile recorder, which has a dynamic range of only 20 dB. The function of the amplitude receiver is to compress the dynamic range of the filter output and to adjust the mean level to produce the most suitable record.

The wide dynamic range in received signal strength is due to a number of factors. A major factor is the increasing attenuation of the transmitted and scattered acoustic energy with height. This is the familiar $1/(\text{distance})^2$ spreading loss. However, as the scattering volume increases with height, the amplitude of the received signal is proportional to 1/(height). In order to compensate for this a receiving system should have a gain which, ideally, increases at a constant rate with elapsed time following each transmission. As well as the spreading loss the acoustic energy is also attenuated by atmospheric absorption at a rate of about 0.5 dB per 30 m at 2500 Hz. Therefore, to compensate for this additional effect, the receiver gain must increase at a faster rate which is no longer linearly related to the time elapsed after transmission. Figure 26 is a typical receiver input signal following a single transmission.

Other factors responsible for changes in received signal level relate to the variability of the atmosphere as a scattering or reflecting medium for the acoustic energy. If there is no turbulence or any temperature gradients present then there will be no scattering, and received signal strength will be below ambient or system noise levels.

The receiver (figure 25) consists essentially of two electronically controlled attenuators followed by a detector and lowpass filter. The attenuators are integrated circuit devices (Motorola type MFC6040). The first one ('Graded Attenuator') produces a repetitive change in system gain, following each

transmission, to compensate for the increasing scattering heights with elapsed time. The attenuator control voltage is derived from the voltage produced across a capacitor as it is being charged by a supply voltage via a high-value resistance. A suitable choice of charging time constant gives a close approximation to the desired gain change characteristic. The capacitor is discharged by a FET switch during each transmission. The second attenuator functions as a normal automatic gain control (AGC) to compensate for changes in the scattering properties of the atmosphere. The AGC time constant is 22 s.

The receiver provides the required detected output for feeding the facsimile recorder as well as pre-detector and AGC voltage outputs. A switch allows either or both of the attenuator systems to be bypassed. Either of the attenuator control voltages can be monitored by a meter. The maximum attenuator input level is 0.5 V rms; consequently each is protected from damage by a pair of diodes.

The receiver bandwidth is controlled by the preceding bandpass amplifier and is therefore 260 Hz. This enables the receiver to cope with doppler shifts of up to ± 130 Hz when connected to one of the inclined outer antennas. When connected to the vertically-pointing centre antenna, the only doppler shifts encountered are those due to vertical movements of air occuring during thermal plume activity. These shifts are usually relatively small and consequently a filter with a narrower passband (20 Hz) can be added to improve the noise performance of the receiver.

19. FACSIMILE RECORDER WRITE AMPLIFIER

The main function of the write amplifier is to use the output voltage from an amplitude receiver to control a high-impedance current source which passes the write current, via a rotating helix, through the wet chemically treated recording paper of a Muirhead facsimile recorder. The recorder can be set, via a gearbox, to a 2-, 4- or 8-s sweep. The acoustic sounder can operate on a 2-, 4- or 8-s transmission period. Any combination of machine sweep and sounder rate is possible but the preferred one is an 8-s machine sweep with a 2-s sounder rate. This results in the minimum rate of recorder paper usage and enables four separate facsimile records, which can be derived from different receivers, to be spaced across the paper. To provide for the various combinations possible, a 4-input multiplexer is built into the amplifier (figure 27). This is controlled by a 2-bit binary code supplied by the sequence generator and timing unit. A switch in a circuit not shown in figure 27, brings 1, 2 or 4 of the multiplexer inputs into operation, enabling 1, 2 or 4 pictures to be spaced across the record. Each input is supplied with a polarity-reversal switch as the recorder is polarity conscious. A LED, associated with each input, indicates which input is connected through at any instant; a necessary setting-up feature.

The write amplifier contains other inputs and circuitry to enable additional information to be placed on the facsimile record. The receiver blanking period is indicated as well as the duration of the transmit pulse. As up to three machines, each supplied by its own write amplifier, may be in use at any one time, a machine number code is inserted in the blanking period to identify the record. On the hour, the record is blanked out for a short period of time and a time code, in BCD format, is inserted in its place. The various timing signals are again supplied by the sequence generator and timing unit, and all of the inputs work on TTL signal levels. When the range-gated integrators are being used to monitor doppler information on a pen recorder, the upper and lower bounds of the sampling height interval can be marked on the facsimile record. This is done by differentiating the leading and trailing edges of the range-gate pulse and, with the aid of steering diodes, making use of the narrow pulses so generated to mark the record. The various features just described can be seen in figures 3 and 28.

20. FACSIMILE RECORDER DRIVE AMPLIFIER

In order to produce a facsimile picture, the rotation of the helix in the recorder must be synchronised with the sounder transmit period. The helix drive comes from a synchronous motor which requires a single-phase 50 Hz supply at about 80 V r.m.s. Synchronisation is achieved by suitably amplifying a 50 Hz reference signal, which is derived from the sequence generator and timing unit, and using this as the supply. The 50 Hz reference is a TTL level square wave and this is filtered in a lowpass filter, to remove harmonics, before being amplified to the required drive level. The circuit of the drive amplifier is shown in figure 29.

21. FACSIMILE RECORDER

The Muirhead facsimile recorder writes by passing an electric current through a wet chemically treated paper via a rotating helix. A three-speed gearbox enables the helix rotation rate to be set at one revolution per 2, 4 or 8 s. A special gearbox had to be built for the purpose as this rate is much slower than the manufacturers of the machine had intended. At the slow rate, the wet feed paper will dry out unless special precautions are taken. To prevent drying, the machine is completely enclosed in a box with a clear perspex front panel which enables the record to be viewed. In addition, a shallow tray filled with water is placed under the machine. This maintains a very humid atmosphere inside the box.

22. LOGARITHMIC AMPLIFIERS

Logarithmic amplifiers(ref.2) are used to monitor the signal strength of the acoustic returns being picked up by each of the five antennas. They derive their inputs from the nonlimiting bandpass amplifier outputs. The circuit of the amplifier is shown in figure 30. It is an a.c.-type logarithmic amplifier based on a Texas Instruments integrated circuit type SN76502. This device has four separate sections, each handling a 30 dB range. The circuit interconnects these sections to provide a theoretical dynamic range of 120 dB. Practical limitations imposed by temperature variations and system noise, however, reduce the useful range to 100 dB or less. The a.c. amplifier is followed by a precision detector and lowpass filter to produce a d.c. output proportional to the logarithm of the a.c. input level. The output versus input relationship is shown in figure 31. The lowpass filter may be switched out if required. Its bandwidth can be set by means of a card-mounted dual-in-line switch to 0.3 Hz, 1.0 Hz, 3.0 Hz or 10 Hz.

23. DOPPLER-TRACKING FILTERS

The functions of the doppler-tracking filter are to provide a further reduction in noise bandwidth, and to produce a d.c. output proportional to the doppler shift which has been given to the acoustic returns. Another important function is to discriminate between genuine acoustic sounding signals and ambient noise, which will continue to produce an apparent doppler output even when the transmitters are turned off. An experienced operator can tell from the appearance of a range-gated doppler record produced on a chart recorder when genuine sounding signals are present, and when they have been reduced below ambient noise levels. In an automated recording system, monitoring 24 hours per day and punching collected data out on to paper tape, however, it is necessary to have an internally generated indication as to whether the current data are to be accepted or rejected.

The typical acoustic return, shown in figure 26, is a difficult signal to work with and imposes conflicting requirements on any doppler-measuring system. Without any doppler shift present it is a signal which undergoes rapid variations in amplitude and phase. With doppler present the frequency shift in the returns may take any value from 0 Hz to more than ± 130 Hz, which is the operating limit of the present equipment. In addition to coping with a fixed doppler shift, if wind shear conditions are present, the doppler shift can undergo rapid changes in the 1 or 2 s following a transmission. In civil aviation the accepted wind shear warning level is 10 kn per 100 ft (approximately 5 m/s per 30 m). In a monostatic acoustic sounder inclined 30° off the vertical and with a transmitter frequency of 2500 Hz, this shear condition produces a rate of change of doppler of 180 Hz per second.

A tracking filter (or phase-locked loop) is one method of extracting the doppler information, which is derived from the d.c. voltage controlling the frequency of the oscillator in the loop. The conflicting requirements mentioned earlier come about by the need to keep the loop bandwidth as small as possible to achieve a further reduction in noise bandwidth, as against the requirements to operate over the relatively wide range of ± 130 Hz, to have a high slew rate to cope with rapidly changing doppler and to have a fast acquisition rate to cope with signal dropouts, all of which require higher loop bandwidth for improved performance. In the final compromise, the integrated noise bandwidth of the tracking filters (twice the integrated loop bandwidth) is about half that of the bandpass amplifiers from which they derive their inputs.

The present form of the tracking filters evolved over a period of several years as more knowledge was gained on the character of the acoustic returns and as requirements on the doppler receiving system became more stringent. It is based on what was originally a first-order phase-locked loop as shown in figure 32. This form was chosen because of its fast acquisition performance; it can theoretically lock onto a signal in one cycle or less. It consists of a phase detector (PD), a voltage-controlled oscillator (VCO) and a lowpass filter (bandwidth 800 Hz) to remove the switching frequency components from the phase detector output. The effect of the lowpass filter on the loop bandwidth is minor. The phase detector output is a linear function of the phase difference between the two inputs and operates from - 180° to + 180°. The loop bandwidth (figure 35) is 18.5 Hz and the lock range ± 52 Hz. The limited doppler range, and a deterioration in performance when near its tracking limit while operating on noisy signals, led to the range-gated integrator concept shown in figure 33. The phase-detector error voltage, applicable to a preselected range-gate height, was sampled, stored, multiplied 100-fold and then added to the VCO control voltage. This forced the mean phase detector error to remain near zero (at the range-gate height) and produced a significant improvement in performance in the presence of noise due to a more symmetrical behaviour in the phase-detector output when phase differences exceeded the limits of ± 180°. The technique also allowed the first-order loop to track doppler shifts well beyond the original limits of ± 52 Hz. The integrator time constant used was 200 s.

The range-gated integrator concept works well but breaks down when wind shear conditions are encountered, and the mean phase detector error is minimised only at the range-gated height. Elsewhere the error increases and performance deteriorates. If the range-gate sampling switch is left permanently closed and the integrator time constant is reduced to say 0.5 s, the phase-locked loop is converted to the more common second-order type. It is freed from the need to range-gate and has the ability to maintain a small mean phase error over a wide frequency range even when operating during wind shear conditions. Loop frequency responses for integrator time constants of 0.5, 1.5 and 6 s are shown in figure 35. The loop is normally operated with a time constant of 0.5 s giving a 3 dB bandwidth of 44 Hz. The disadvantage of the increased noise bandwidth, compared with that of the first-order loop, is tolerated in order to maintain fast

acquisition time and slew rate. The presence of the X100 amplifier produces a large increase in the theoretical lock range over that of the first-order loop; however, this is restricted, by amplifiers limiting, to a range of 2280 Hz to 2690 Hz. Similarly the mean phase detector error is reduced by a factor of 100. Figure 36 shows the output voltage versus input frequency relationship of the tracking filter.

Figure 37 is a circuit of the tracking filter. The integrator section (on the righthand side) which converts the first-order loop to a second-order loop, is actually on a separate circuit card and is one section of a standard range-gated integrator, described in the next section. The appropriate time constant is selected and the range-gating function disabled. The input signal is hard limited by an LM311 voltage comparator before being passed on to the phase detector. The phase detector is a digital type based on an SN7400 quad Nand gate, an SN74121N monostable and an SN7474 'D' type flip-flop. In conjunction with a lowpass filter it gives a linear output over a phase difference input range of ± 180°. The lowpass filter is a four-pole active type with a 3 dB bandwidth of 800 Hz. The VCO is based on the ICL8038 integrated circuit. A front-panel control allows easy adjustment of mid-range frequency. Doppler, lowpass filter and VCO outputs are provided.

The need has already been mentioned, in an automated recording facility, to have the ability to reject bad data. The 'Lock Indicator', shown in the circuit of the tracking filter, provides an output which can be calibrated to give a reasonable indication of the signal-to-noise ratio of the input signal to the loop. The lock indicator output, as well as the doppler output, is fed to the microcomputer, which accepts or rejects the doppler output depending on whether the lock indicator is below or above a predetermined value. The lock indicator works only when the loop is in a second-order configuration and makes use of the fact that the phase detection output remains close to zero when tracking a clean signal in the frequency range ± 130 Hz. When the signal becomes noisy the phase detector output also becomes noisy, but the mean value still remains near zero. If the noisy phase detector output is fed into a fullwave a.c. detector and lowpass filtered, the resulting d.c. output can be calibrated to give an indication of the input signal-to-noise ratio. In the circuit of figure 37, an output from the 800 Hz lowpass filter is fed to a precision fullwave detector combined with a simple 10 Hz lowpass filter. The output of this filter is the 'Lock Indicator' output. This output is also compared with a preset threshold voltage, by means of a voltage comparator which then illuminates a LED to give a visual indication of poor signal conditions. Graphs in figures 38(a) and 38(b) show how the lock indicator output voltage varies with input signal-to-noise ratio measured at the (nonlimiting) output of the ± 130 Hz bandpass amplifier, from which the tracking filter derives its input. The graphs show curves for loop integrator time constants of 0.5, 1.5 and 6 s and for input signal frequencies of 2500 Hz and 2400 Hz, the latter representing a doppler shift of 100 Hz. Despite the relatively large difference in operating frequencies the corresponding plots for the two frequencies are closely matched at the threshold signal-to-noise level. This would be in the vicinity of 0 dB if the desired signal was constant in phase and frequency. Because of the dynamic nature of the acoustic return signal, however, the threshold signal to noise ratio is set 6 dB higher than would otherwise be the case. Figure 38a and 38b also show the doppler output response during the same test conditions.

24. RANGE-GATED INTEGRATORS

Six circuit cards, each containing four range-gated integrators, provide a total of 24 independent circuits which can be used for a variety of monitoring and control functions. Five of the circuits, with the range-gating facility

disabled, are permanently connected to the tracking filters to provide the second-order loop function. Their main function, however, is to sample doppler outputs at specified heights so that they can be monitored on a chart recorder. Similarly, they facilitate the resolution of wind components, which requires doppler sampling from three separate antennas transmitting at different times. They have also been used in closed loop control functions, such as transmitter beam-steering in angle-of-arrival investigations.

The circuit of the integrator is shown in figure 39. It is basically a simple RC filter with an integrated circuit FET switch in the input. A card-mounted switch provides a choice of eight time constants ranging from 0.5 s to 200 s. Two buffered outputs provide a choice of output gain; X1 or X100. On the hour, an hour-marker input momentarily discharges all integrator capacitors. They can also be individually shorted out by means of a switch. Each of the 24 circuits can be connected, by means of an external switching facility, to any one of four independent range-gate time signals. The 24 circuits are also grouped together in pairs by the dual FET switches, whose 'Inhibit' inputs can be connected to any one of several timing signals generated by the sequence generator and timing unit for this purpose. This arrangement ensures that an integrator samples only after the appropriate antenna has transmitted and not after any other. LEDs are illuminated when sampling occurs and when each pair of circuits is inhibited, a feature which greatly assists setting up new recording or experimental configurations.

25. REAL TIME MONITORING

Real-time monitoring is provided by two pen recorders each of 6 channel capacity. These record wind direction and speed from an anemometer mounted on a 10-metre tower, and also air temperature. By means of the range-gated integrators they record a variety of data, such as doppler at one or more heights, resolved wind components and angle-of-arrival information.

26. RANGE-GATE GENERATOR

The range-gate generator (figure 40) provides pulses, with independently adjustable start and stop times, which are synchronised with the acoustic sounder transmit rate. It's main purpose is to control the sampling interval of the range-gated integrators. Four independent circuits are provided in the generator, each supplying a pair of complementary outputs. Timing is achieved by counting clock pulses supplied by the sequence generator and timing unit. The clock frequency is 50 Hz, 25 Hz or 12.5 Hz, depending on whether the transmit rate is once per 2, 4 or 8 s. The count is reset to zero at each transmission. Selection of start and stop times is made by two pairs of decade switches which provide 100 possible times. The smallest gate time possible with this arrangement is 20, 40 or 80 ms, depending on whether the transmit rate is one per 2, 4 or 8 s.

27. WIND COMPONENTS RESOLVER

The wind components resolver (figures 41(a) and 41(b)) enables the doppler outputs from the various inclined antennas to be combined and resolved into new outputs, which are proportional to two horizontal wind components, and a vertical velocity. The wind components are North-South and East-West. With the aid of range-gated integrators to ensure sampling at the selected height level, and also during appropriate parts of the transmitting sequence, the resolver enables wind components at the selected height to be continuously monitored on a chart recorder.

The indicated doppler from any inclined antenna is the combined result of both vertical and horizontal movements of air resolved along the axis of the antenna. In bistatic sounder operation, due to the particular geometry employed, the inclined doppler is almost four times more sensitive to vertical air movements as it is to horizontal movements. In hot weather during vigorous thermal plume activity, vertical doppler shifts of up to 50 Hz, corresponding to a vertical velocity of 3.4 m/s, have been observed. It is therefore necessary to remove the vertical contribution during the resolution of the wind components. The resolver does this by taking the doppler outputs of two or more antennas and adding and subtracting them in certain proportions to achieve the resolution. The resolver consists of two separate circuits. The first (figure 41(a)) is intended for bistatic operation and operates only on the inclined antenna. The second (figure 41(b)) is used on monostatic doppler and requires two inclined antennas together with the centre vertical antenna, which must be used in this case to provide the information necessary to remove the vertical component from the inclined doppler outputs.

28. SURFACE METEOROLOGICAL UNIT

The surface meteorological unit provides data for visual display and for recording. Analogue voltages proportional to wind speed, temperature and barometric pressure are displayed on calibrated panel meters, while light emitting diodes show the octant from which the wind is blowing. Outputs are provided which enable the meteorological data to be sampled by the 32-channel, analogue-to-digital data conversion system for subsequent punching on to paper tape together with the acoustic sounder wind data. The anemometer used is a standard Bureau of Meteorology type. Temperature is measured using a National LX5600 temperature transducer. The air pressure is measured using a National LX3700 temperature-stabilized, piezolelectric, absolute pressure transducer. Reference 3 contains additional information and circuits.

29. SEQUENCE GENERATOR AND TIMING UNIT

The sequence generator and timing unit produces the transmit sequences and all the timing and synchronisation signals necessary for the operation of the equipment. It also provides system status information to the microcomputer to enable it to select the appropriate program from its memory to process the data entering via the 32-channel multiplexer. The eight-bit status information is derived from a switch register, comprised of eight toggle switches, mounted on the control panel.

The microcomputer, based on the Intel 8008 microprocessor, could have been programmed to carry out the control and synchronisation functions. However in an experimental system the separation of control and data processing gives greater flexibility and scope for short duration experiments without the necessity of reprogramming the computer.

Timing is derived from a single 1 MHz crystal oscillator. The microcomputer, which generates its own clock frequency and works asynchronously with the control system, is the only item of equipment which is not referenced to this oscillator.

The sequence generator and timing unit carried out the following functions:

(a) It selects the antenna which is to transmit the acoustic energy into the atmosphere and, if more than one is involved, controls the transmitting sequence.

(b) It controls the various relay operate times in the transmit/receive changeover units.

(c) It controls the transmit pulse width.

(d) It controls the receiver blanking time.

(e) It generates a modulation envelope to help prolong transducer life-time.

(f) It provides a selection of inhibit signals to control the range-gated integrators.

(g) It provides one of three clock frequencies for the range-gate unit.

(h) It provides a 50 Hz reference input to synchronise the facsimile-recorder drive.

(i) It provides a two-bit coded input signal to control the four-input multiplexer in the facsimile-recorder write amplifiers.

(j) It provides a clock giving time of day.

(k) It generates hour markers.

(l) It generates machine number identification markers which are placed on the facsimile records.

Figure 7 is a photograph of the unit together with the microcomputer. Figure 42 shows the front panel layout. The upper-left corner contains the eight-bit switch register which controls the mode of operation. To the right are the digital clock display and time setting switches. Below is a diamond pattern of five LEDs corresponding to the antenna layout. The appropriate LED flashes when that antenna transmits. On the bottom-left are computer control switches, a transmit pulse length control (50, 100 and 150 ms) and a variable receiver-blanking time control.

The last three switches in the eight-bit register (righthand end of row) control the transmit mode and provide sense lines to the microcomputer to enable it to select an appropriate data-processing program from its memory. The current operating modes and corresponding binary switch positions are as follows:

000 Multimode - A 2-min data average punched out on to paper tape every 2 min
001 Transmit from centre antenna only
010 Multimode - A 2-min data average punched out on to paper tape every 8.5 min
011 Multimode - A 2-min data average punched out on to paper tape every 17 min
100 Transmit from centre antenna only
101 Transmit from North or South antenna only
110 Transmit from East or West antenna only
111 Transmit from centre antenna only
(1 - switch up, 0 - switch down)

Multimode is a four part transmit sequence as follows:

1. Centre (Repeat)
2. North or South
3. Centre
4. East or West

The next two bits in the switch register control the pulse repetition frequency (PRF) or transmit rate:

00 One pulse/2 s
01 One pulse/4 s
10 One pulse/8 s
11 No transmission - system in receive mode

The following two bits control which of the North-South and East-West antennas will transmit if required to do so:

N-S 0 South antenna
1 North antenna

E-W 0 West antenna
1 East antenna

The final bit in the register (lefthand side) is the computer enable switch which enables data processing to commence. The three switches below are also part of the computer control system.

The electronic circuitry is wired on six circuit cards and on the front panel. Essentially, the circuitry can be divided into 7 sections:

(a) the front panel,

(b) a programmed read-only memory (ROM) transmit sequence generator,

(c) a programmed ROM relay pulse-sequence generator,

(d) a crystal oscillator and divider,

(e) a clock giving time of day,

(f) time and recorder number coding for the facsimile recorders, and

(g) a programmed ROM shaped modulation pulse generator for controlling the transmitter output.

For further information and circuits see reference 4.

30. DATA COLLECTION AND PROCESSING EQUIPMENT

The following is a brief description of the data collection and processing equipment. A more complete description, including circuits, is given in reference 5. Figure 43 is a block diagram of the 32-input multiplexer, analogue-to-digital converter, microcomputer and output recording facilities.

The eight-bit switch register, in the sequence generator and timing unit, provides control data via a digital multiplexer and input port 1, which enables the microcomputer (based on an Intel 8008 microprocessor) to select the appropriate program from its memory to process the incoming data. Other status signals such as Paper Tape Punch Ready, FIFO (first in first out) Buffer Output Ready and Transmitter Pulse Width are also fed to input port 1 via the digital multiplexer. Acoustic sounder analogue data are fed to a 32-input multiplexer and hence to an analogue-to-digital (A/D) converter. Data conversion is initiated by the transmit pulse which resets the multiplexer address to zero and starts the address sequence. The transmit pulse is also fed to the microcomputer, via the Interrupt Control, to initiate program sequences. When a conversion complete signal is produced by the A/D converter, the digital word is stored in a FIFO buffer, the multiplexer address increments and a new conversion is started. This process continues until all 32 channels have been sampled, converted and stored in the FIFO buffer. When all 32 data words have been entered in the buffer, an output ready signal indicates to the computer that it can read and store the input data. The multiplexer cycles every 50 ms and each cycle is completed in 10 ms. (As the multiplexer cycles every 50 ms irrespective of whether the sounder is transmitting every 2, 4 or 8 s, the microcomputer must average every 2, 4 or 8 consecutive samples of data from each channel in order to divide the operating height range into 20 height intervals).

Processed data are punched onto paper tape via output port 2. Time information is also punched onto the paper tape. Both the processed data and the time information are fed to a common bus feeding the punch via separate tri-state buffers. These buffers are controlled by output port 3. Two channels of information are also fed to an XY recorder via output porta 0 and 1. The digital

data are converted to analogue form by converters and then lowpass filtered before reaching the recorder. The recorder is used to draw doppler versus height profiles during the interval when a frame of data is being punched out onto paper tape.

31. MICROCOMPUTER SOFTWARE

The microcomputer programme is stored in 256 byte, programmable read-only memories (PROMs), which are programmed electrically and can be erased using ultraviolet light. Eight PROMs, corresponding to eight memory 'pages' (designated 0 to 7) respectively, give a total capacity of 2048 bytes. An additional four, 256 byte 'pages' of random-access memory (RAM) are employed to store meteorological and acoustic sounder data. A scratch pad memory containing an accumulator (A register) and six, eight-bit registers designated B, C, D, E, H and L, which may be used for temporary storage, are also available in the 8008 central processing unit (CPU). Registers H and L are loaded with the required 'page' and 'page address' respectively, for instructions involving operations with external memory (PROM or RAM).

A RESTART instruction, in conjunction with the internal INTERRUPT facility is employed to initiate the main programme, stored on (PROM) 'page' 1. The RAM is initially cleared and output ports 0 and 1, which provide data for the XY plotter, are set to zero. The switch register in the sequence generator and timing unit is then examined (on input port 1) to determine the mode of operation and pulse-repetition period, and relevant parameters (addresses of the data processing, plotting and punching routines and the number of consecutive frames of data to be averaged) are stored in RAM.

Processing of acoustic-sounder and meteorological data from the 32-channel multiplexer is initiated, following each transmitted pulse, using the external INTERRUPT facility to reset the programme to a fixed address on 'page' 1. Appropriate RAM locations employed for counting are reset, and the address of the programme to process the data from a particular receiving antenna (determined by examining the 'status' register on input port 1) is stored in memory. Samples of data are subsequently entered on input port 0 and added to memory to give information from 20 height intervals or 'range-gates'. Five levels are stored on each of the four 'pages' of RAM.

The acoustic-sounder data from a given receiving antenna are sampled in the order; lock-indicator output, doppler output and logarithmic-amplifier output. Two additional channels for angle-of-arrival data are also provided for the centre antenna. If the lock-indicator voltage is below a predetermined threshold (equivalent to a signal-to-noise ratio above 6 dB), the doppler sample is added to memory and a counter indicating the number of 'good' data samples is incremented. Doppler data are not accepted if the signal-to-noise ratio is below the required threshold.

When the required number of frames of data has been processed (64 for one acoustic transmission every 2 s), the doppler and logarithmic amplifer data stored in memory are averaged, and the punching and plotting routines are initiated. A 200 (octal) code (indicating a new block of data) is punched on the paper tape, followed by the 'switch' and 'status' registers, time in hours and minutes and meteorological data (surface pressure, temperature, wind speed and direction). Acoustic-sounder data from 20 height intervals are then punched in the order; lock indicator, averaged doppler, number of 'good' data counts and averaged logarithmic-amplifier output for each of the receiving antenna configurations employed in a given mode of operation. Provision is also made for two additional channels of angle-of-arrival information in the case of the centre antenna. Including the centre antenna, seven sets of monostatic and bistatic information are punched out in each block of data. Selected channels of averaged doppler

data are also plotted as profiles on the XY recorder after the paper chart has been advanced about 12 mm. Control is then passed back to the main programme to clear or reset relevant memory locations and to begin a new, two-minute average.

32. COMPARISON OF SOUNDER DATA WITH MEASURED WIND VELOCITY

The ideal method to check the accuracy of the sounder data would be to have many wind anemometers mounted at regular intervals up a 300 m tower in close proximity to the sounder facility. Unfortunately such a tower was not available, but advantage was taken of the opportunity to use an alternate method of measurement. A separate project, operating at the same site, required hourly launching of temperature measuring meteorological balloons over a 24 hour period. Each balloon was tracked from ground level by a pair of theodolites separated by a known distance. Angular information from each theodolite was processed electronically and punched onto paper tape at one second intervals. Computer analysis of the tape gave the position of each balloon as a function of the elapsed time from launch and hence its horizonal velocity, resolved into North-South and East-West components, as a function of height above ground. The balloons were approximately 1.5 m in diameter and it was assumed, because of their size and low mass, that each measured horizontal velocity was close to the true wind velocity. Night tracking was aided by a light attached to each balloon.

Balloon velocity data obtained from two daylight launches and four night launches are shown in figures 44 and 45(a) and (b). In each case the resolved North-South and East-West components are given. Wind velocity data derived from the acoustic sounder, operating in a monostatic mode, have been superimposed on these plots. The sounder data shown in figure 44 shows consecutive two minute averaged data profiles obtained from the microprocessor controlled data recording system. One profile was recorded immediately before the balloon launch and the other following it. In figures 45 (a) and (b) the sounder data are shown as discreet points, which are derived from the chart of a multi-channel pen recorder which gave North-South and East-West doppler at two range-gated height intervals. Averaging in this case was by RC integration.

This was a once only opportunity to calibrate the acoustic sounder. However, conditions were far from ideal. Winds over the entire 24 hour period were light and variable; generally less than three m/s. Thermal plume activity during the hours of sunlight introduced a large vertical component into the received doppler and caused large spatial variations in the general air movement. Consequently, most of the useful data were gathered during the hours of darkness when vertical air movement was minimal. During this period the balloon tracking data revealed a double shear condition at very low altitude. Wind velocity at ground level varied from 0 to 2 m/s and increased rapidly to 4 to 6 m/s at a height varying from 50 to 150 m. It then fell off rapidly, passing through 0 m/s and then increased to 2 to 6 m/s in the opposite direction. Steady winds of 8 to 10 m/s would have been preferred for this accuracy test.

A further problem encountered was the weak acoustic returns received during most of the launch period. During the night they tended to occur in one or two narrow, low level horizontal bands which varied in height. This required continual adjustment of range-gate heights to obtain the best signal conditions for measurement. In the first profile of figure 45(a) data from two range-gate heights are shown. In the second profile, and in those of figure 45(b), only one range-gate height could be used to extract a sufficiently strong signal to make a valid measurement.

The sounder profiles shown in figure 44 were produced in the middle of the day when thermal plume activity was present. Information from the vertical sounder was used to extract the vertical component from the doppler outputs of the inclined sounders. This left the horizontal components which were scaled

and plotted in the figure. At medium altitudes there is good agreement between the sets of East-West data, apart from a sudden dip in the sounder velocity at 120 m in the 1300 p.m. profile. The North-South values are very low and the agreement between the sets data is poor. Aircraft engine noise from the far side of the airfield may have been responsible for the deviations.

In figures 45(a) and (b) the range-gated data points shown on the profiles for 0000 a.m. and 0700 a.m. match well with the tracking data despite the wind shear evident. The match for the profiles of 0200 a.m. and 0300 a.m. is not as good. It should be noted, however, that because of the magnitude of the shear, a variation in its height above the launch site and above the sounder site, of as little as 10 m, would have a considerable effect on the measured wind values. The launch site was several hundred m away from the sounder site.

33. CONCLUSION

The DRCS acoustic sounding facility at Edinburgh Airfield has been developed as part of the DRCS contribution to a task involving the usefulness of remote sensing techniques for the determination of wind profiles in the lower atmosphere as an aid to aircraft operations. The facility is configured to enable the simultaneous comparison of the performance of three techniques of acoustic sounding in identical weather conditions. The three techniques are monostatic doppler operation, bistatic doppler operation and angle-of-arrival operation. The angle-of-arrival operation was unsuccessful due to the inadequacies of the antenna employed and a lack of knowledge concerning the true nature of the complex reflected acoustic wave front entering the antenna.

The antenna configuration, electronic equipment and performance parameters as well as the data collecting system and processing equipment have been described in detail.

34. ACKNOWLEDGEMENTS

The completion of the facility in the allotted time scale involved a tremendous effort from the staff of TS Group. Messrs M.G. Rawolle, J.H. Silby and M.L.J. Raymond designed most of the electronic equipment, while Mr. A.R. Mahoney developed the software for the microcomputer. Valuable support was given by Messrs J.C. Crombie, L.R. Laming, R.G. Pullen and the workshop staff. The author gratefully acknowledges the efforts of all concerned.

REFERENCES

No.	Author	Title
1	Mahoney, A.R.	"Remote Acoustic Wind-Sensing Experiments". WRE-Technical Report-1814(A), April 1977
2	Rawolle, M.G.	Logarithmic Amplifier for Fixed Site Sounder. Private communication
3	Silby, J.H.	"Edinburgh Wind Sensing Facility - Surface Meteorological Unit". Private communication TS Group Working Paper No.2(d)
4	Silby, J.H.	"Control System - Fixed Site Acoustic Sounder". Private communication TS Group Working Paper (in preparation)
5	Raymond, M.L.J.	"A Microprocessor Controlled Data Acquisition Unit". WRE Technical Memorandum (in preparation)

APPENDIX I

EQUIPMENT SUMMARY

Item	No.	Comments
Antennas	5	2 m diameter parabolic reflector fitted with acoustic transducer.
Transmitters	2	Electrical output 100 W Frequency 2500 Hz Pulse width 50, 100, 150 ms Pulse rate 1 per 2, 4 or 8 s.
Control Unit	1	Transmit and recording mode controlled by an 8 bit switch register.
Rx/Tx Units	5	Electromagnetic relay operation.
Preamplifiers	6	5 doppler units, gain 53 dB 1 angle-of-arrival unit.
Bandpass Amplifiers	8	Centre frequency 2500 Hz Bandwidth 260 Hz Output 1 40 dB gain Output 2 80 dB gain with limiting.
Logarithmic Amplifiers	5	Dynamic range 100 dB.
Tracking Filters	8	Tracking range: 2280 Hz to 2690 Hz (limited by amplifier saturation) 3 dB loop bandwidth: 18.5 Hz to 44 Hz.
Range-Gate Generator	1	4 independent outputs.
Range-Gated Integrators	6	4 circuits in each unit.
Amplitude Receivers	3	
Write Amplifiers	2	1, 2 or 4 multiplexed inputs.
Recording Interface	1	32-input multiplexer Inputs: Doppler Lock indicator Logarithmic amplifier Angle-of-arrival Meteorological data.
Processing Equipment	1	8008 microcomputer
Recording Outputs	1 1 2	Paper tape punch XY plotter Facsimile recorders.

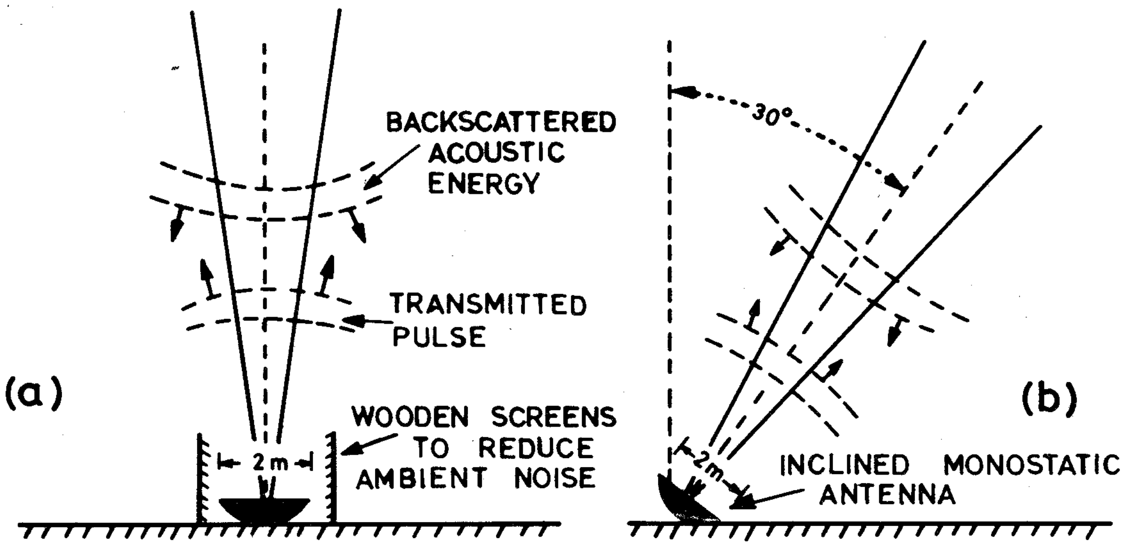


Figure 1. Vertical (a) and inclined (b) acoustic antenna configurations employed for monostatic wind measurements

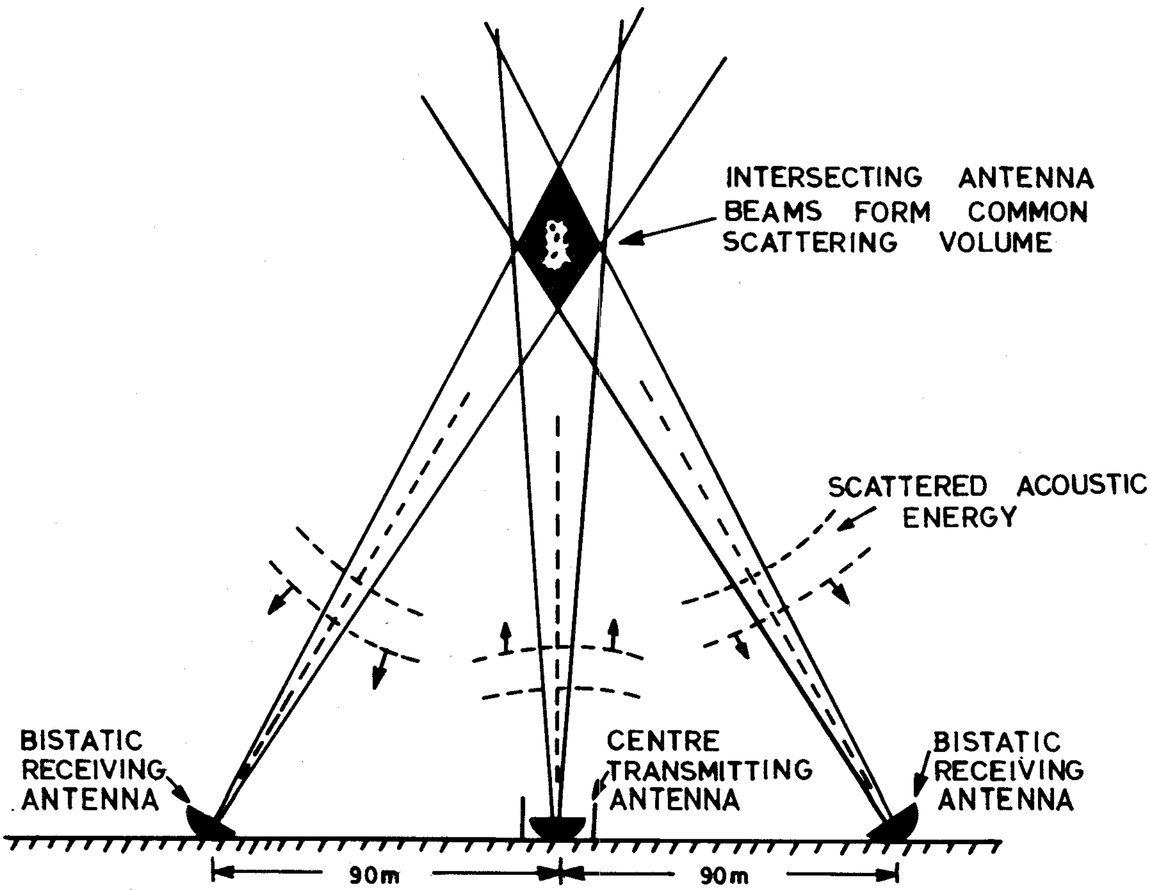


Figure 2. Acoustic antenna configuration employed for bistatic wind measurements

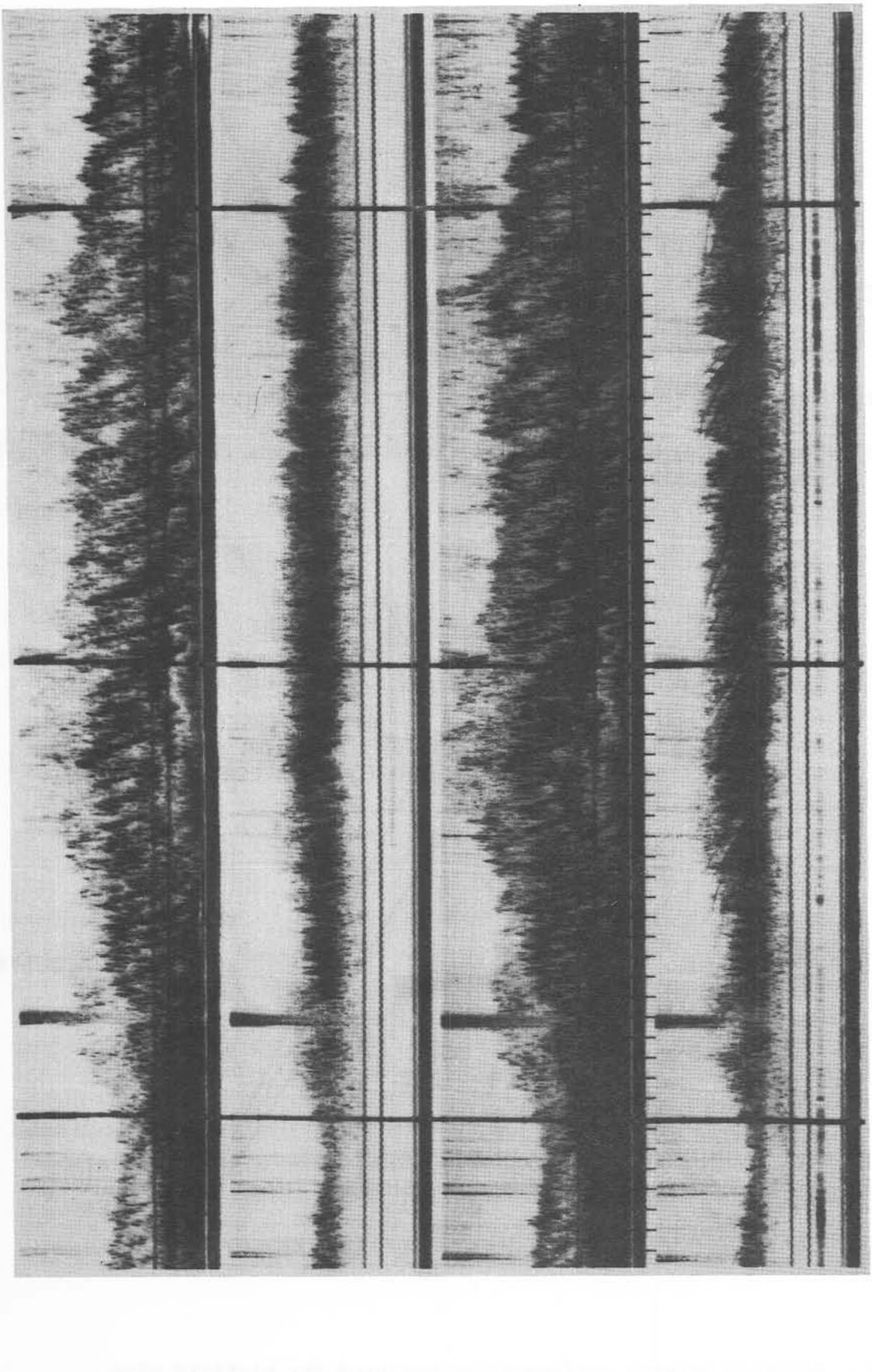


Figure 3. Facsimile sounder record obtained from centre antenna during multimode operation

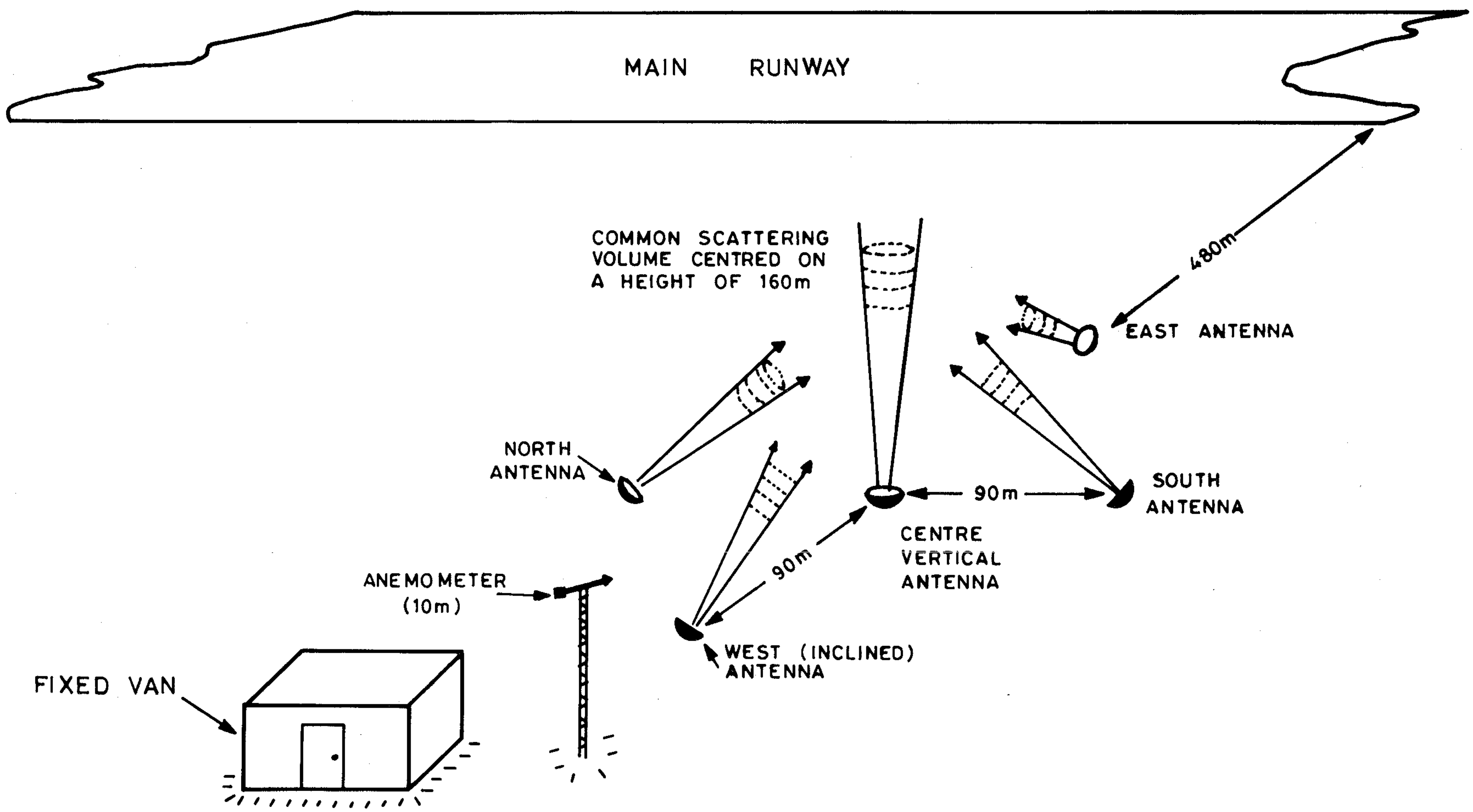


Figure 4. Configuration employed for the experimental acoustic wind sensing facility at Edinburgh Airfield

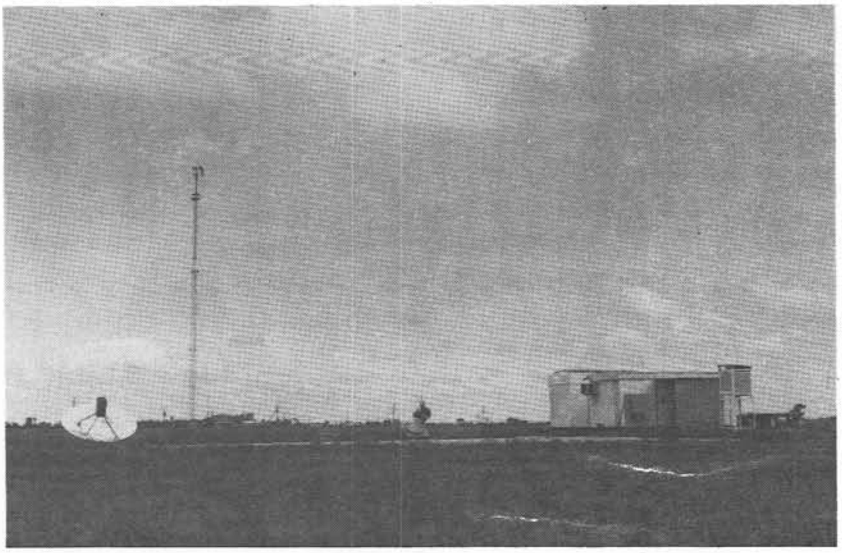


Figure 5. Photograph showing the electronics van, meteorological tower and the West antenna

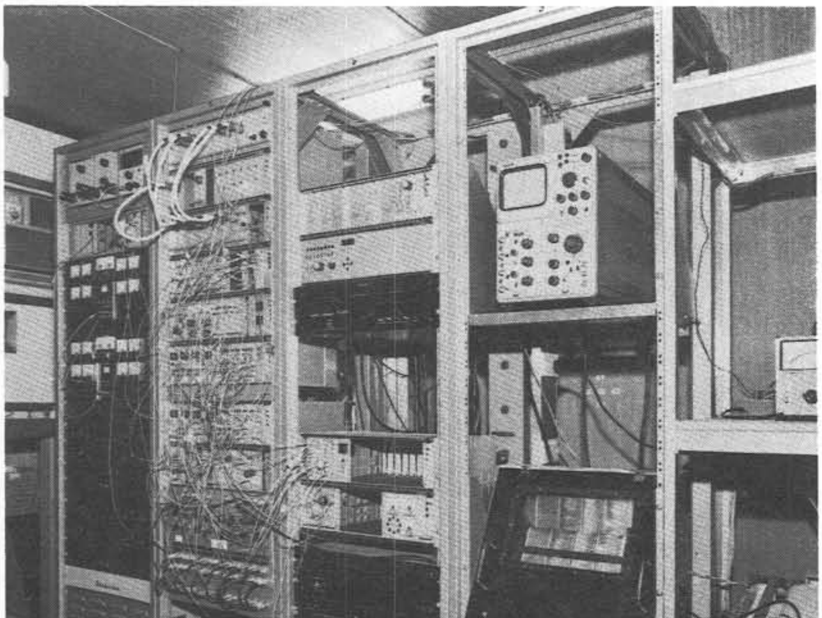


Figure 6. Photograph showing the transmitting, receiving and recording equipment inside the electronics van

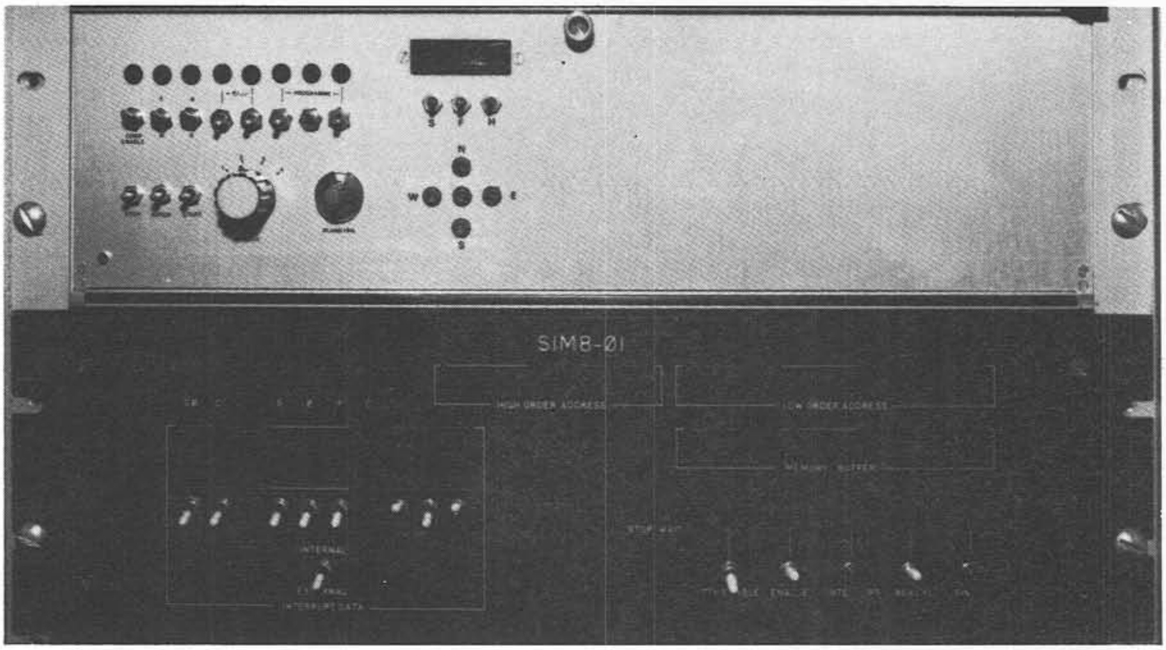


Figure 7. Photograph showing the sequence generator and timing unit (top) and the microcomputer

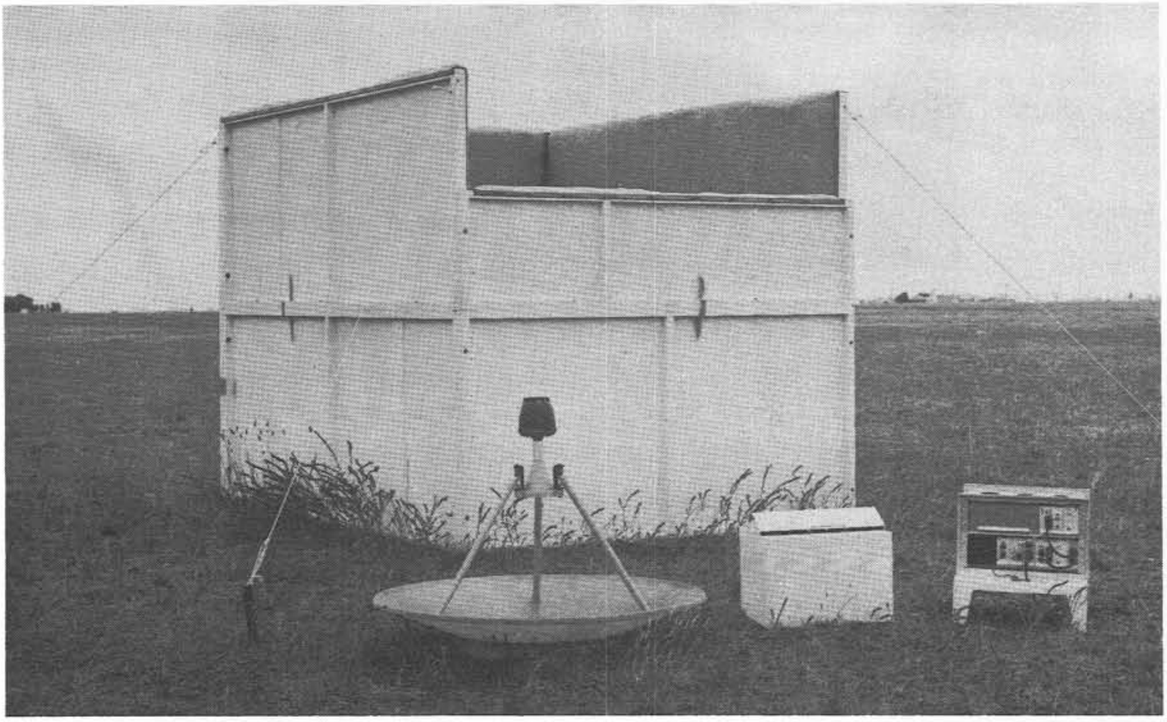


Figure 8. Photograph of an antenna screen. (The equipment in the foreground is not related to this Report)

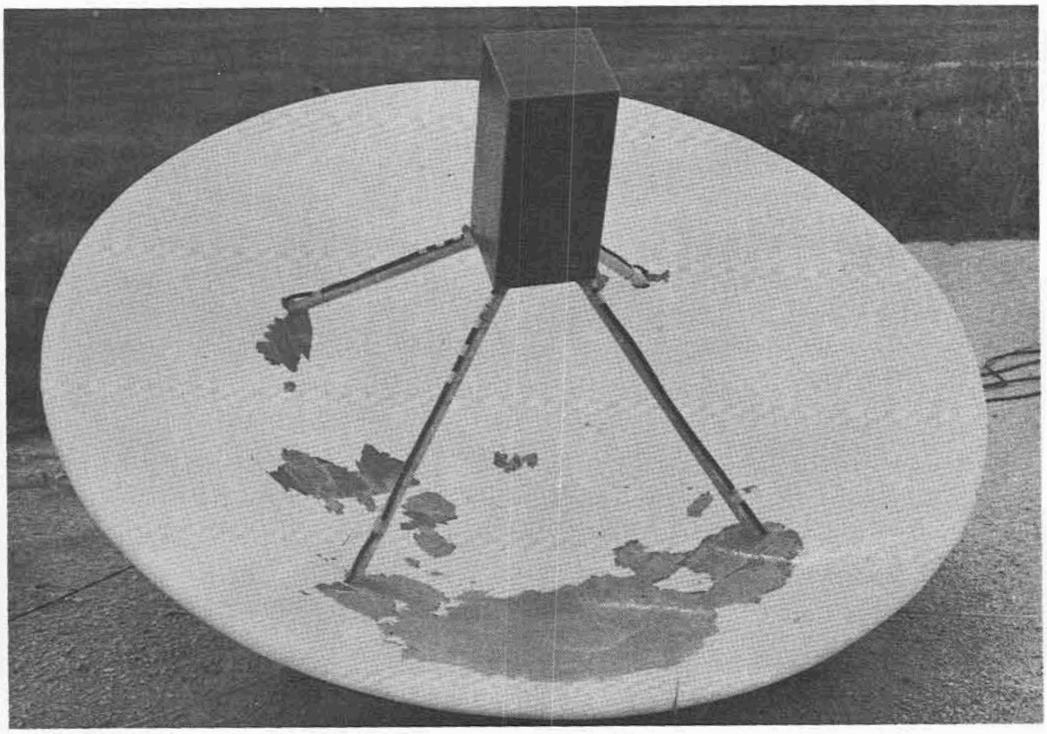


Figure 9. Photograph of an inclined antenna

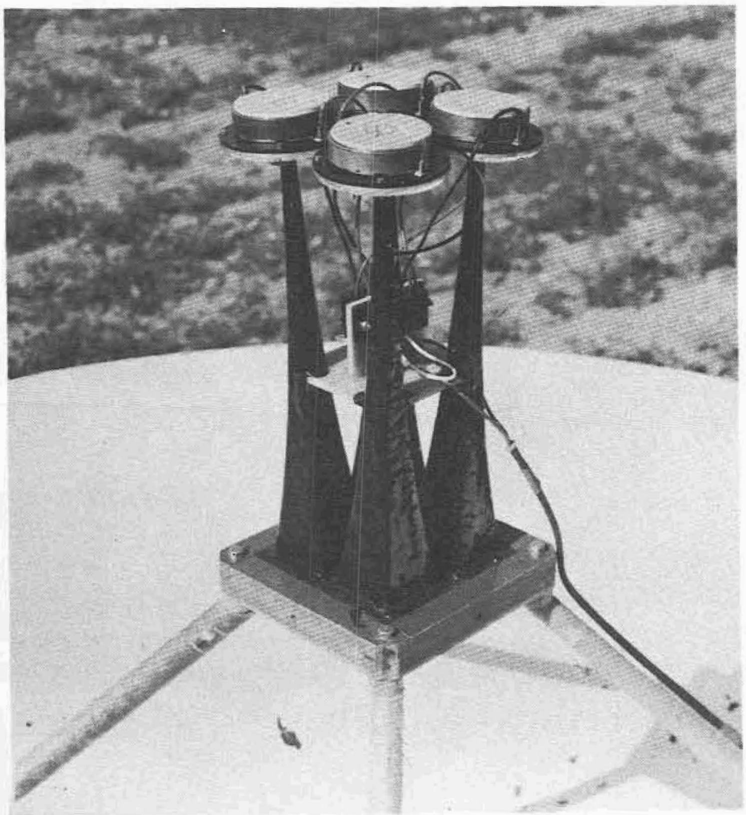


Figure 10. Photograph of the transducer assembly

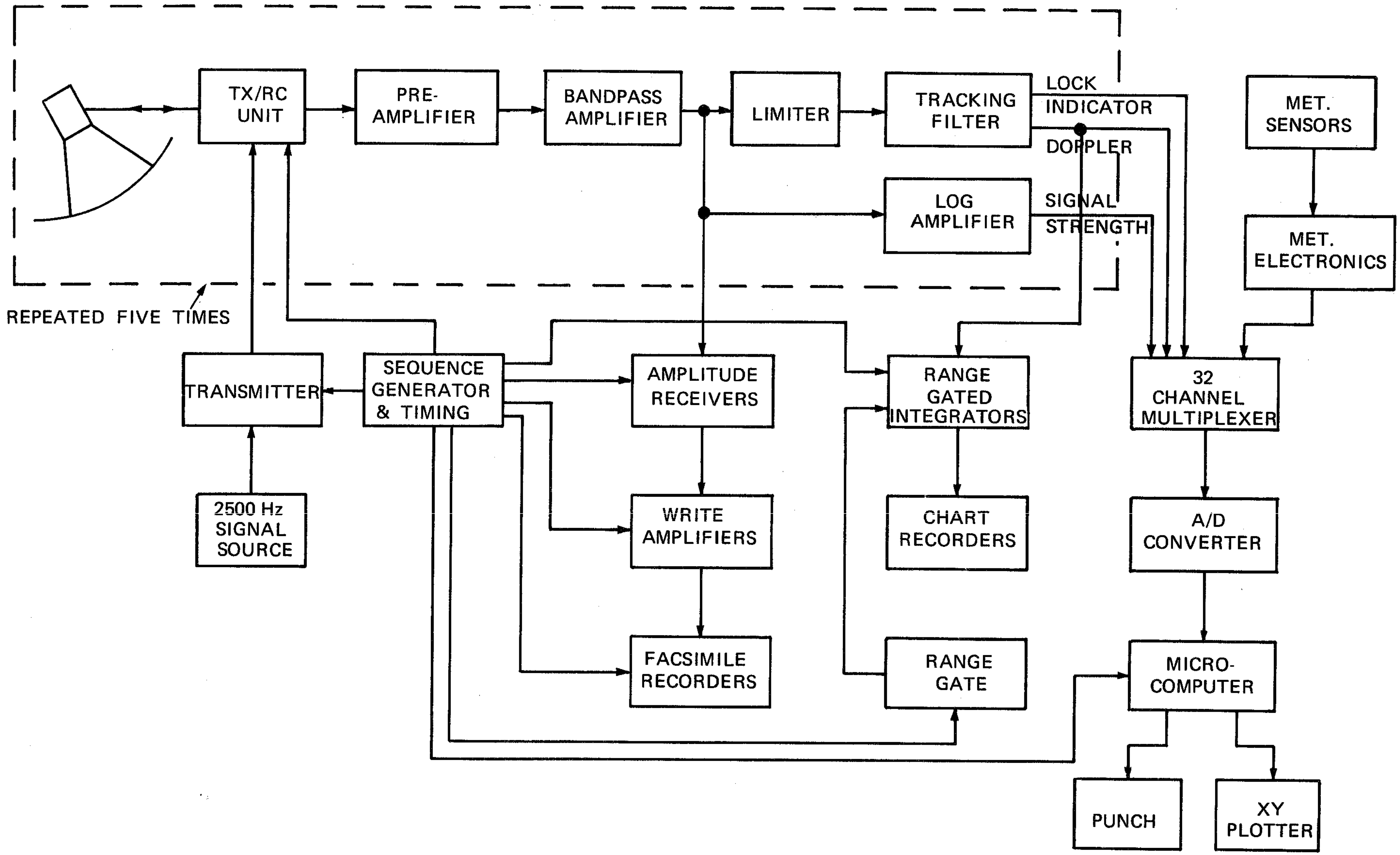


Figure 11. Doppler configuration and recording system

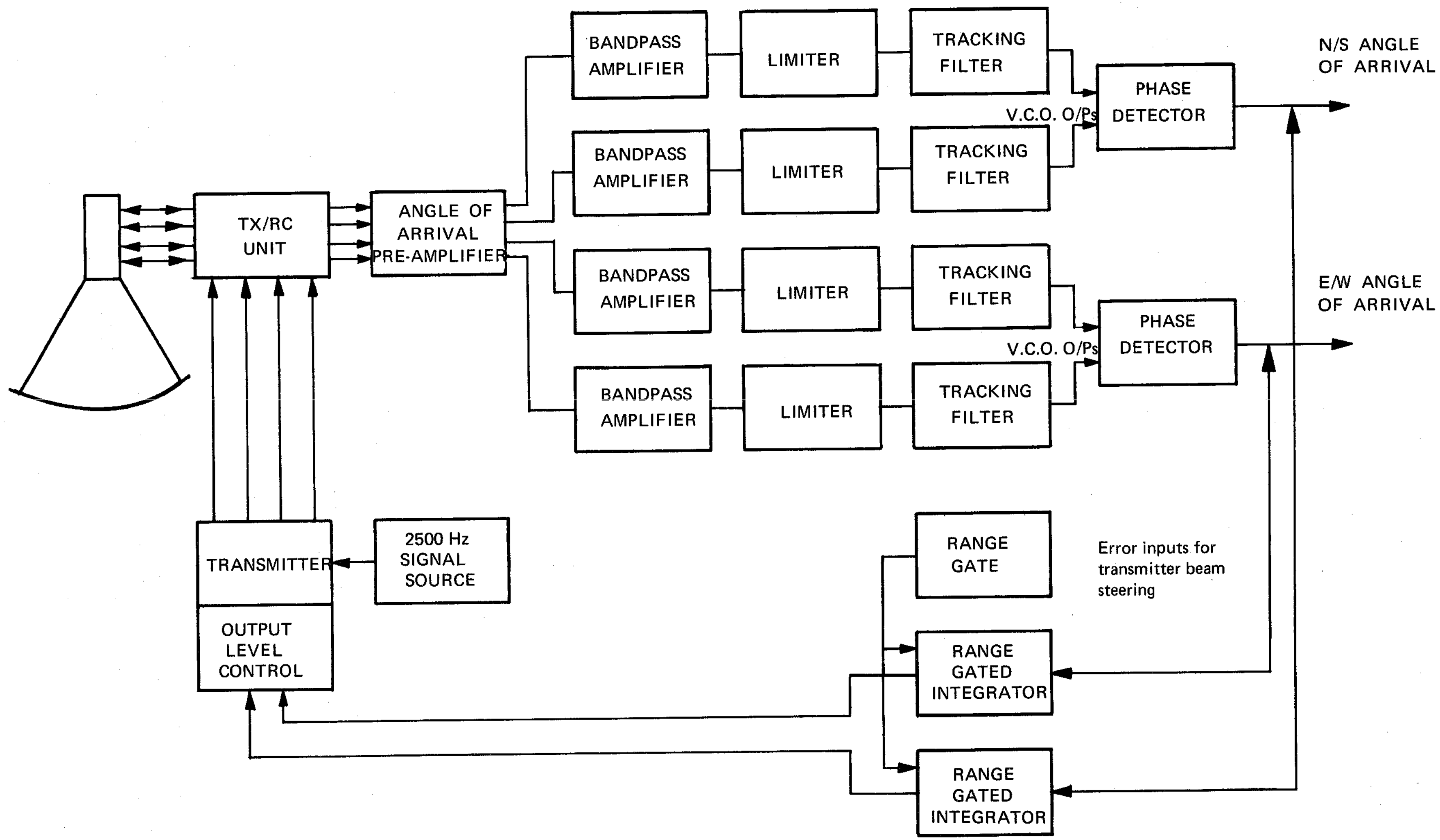


Figure 12. Angle-of-arrival configuration

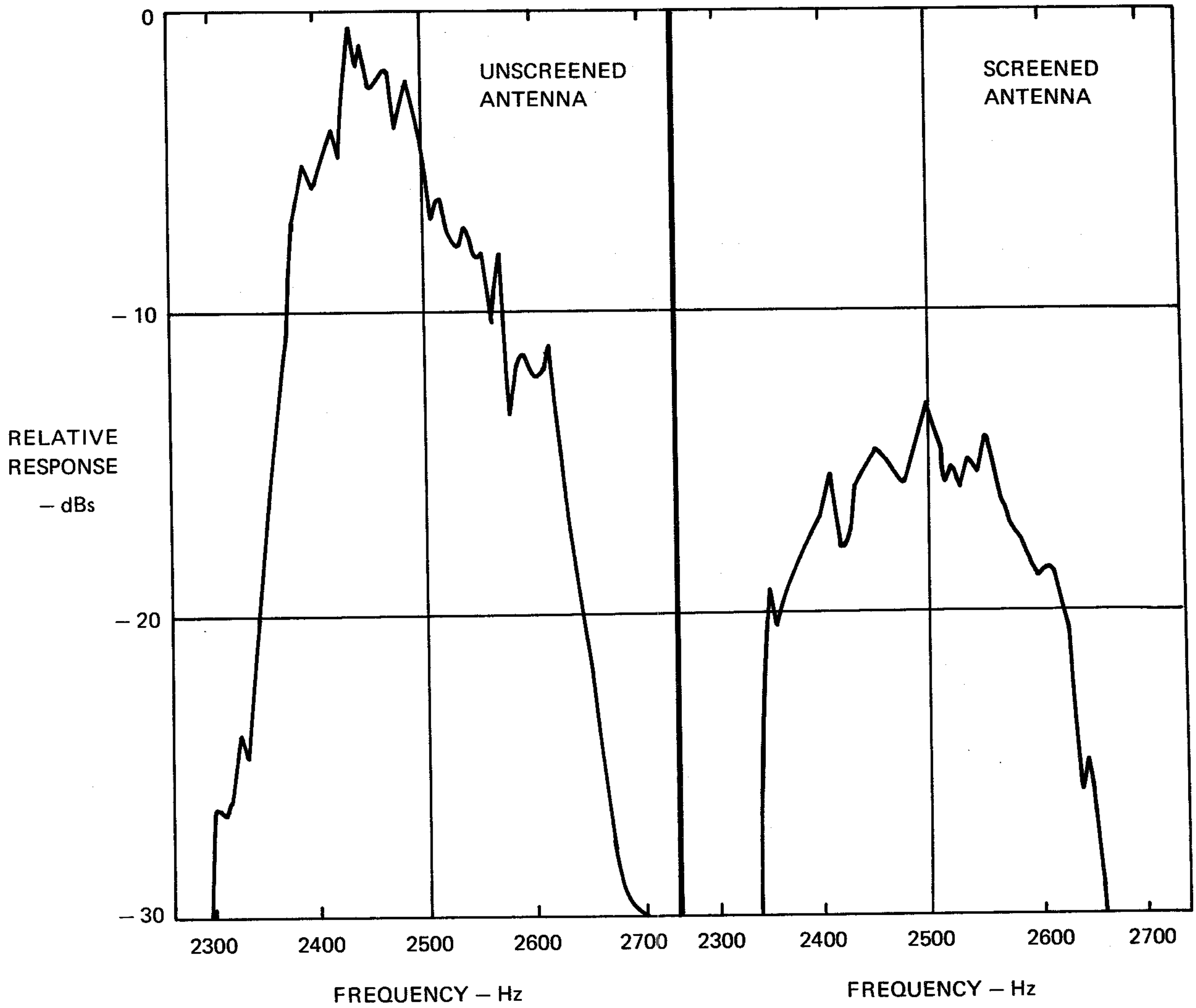


Figure 13. Ambient noise frequency spectra from unscreened and screened antenna (Measured at bandpass amplifier output)

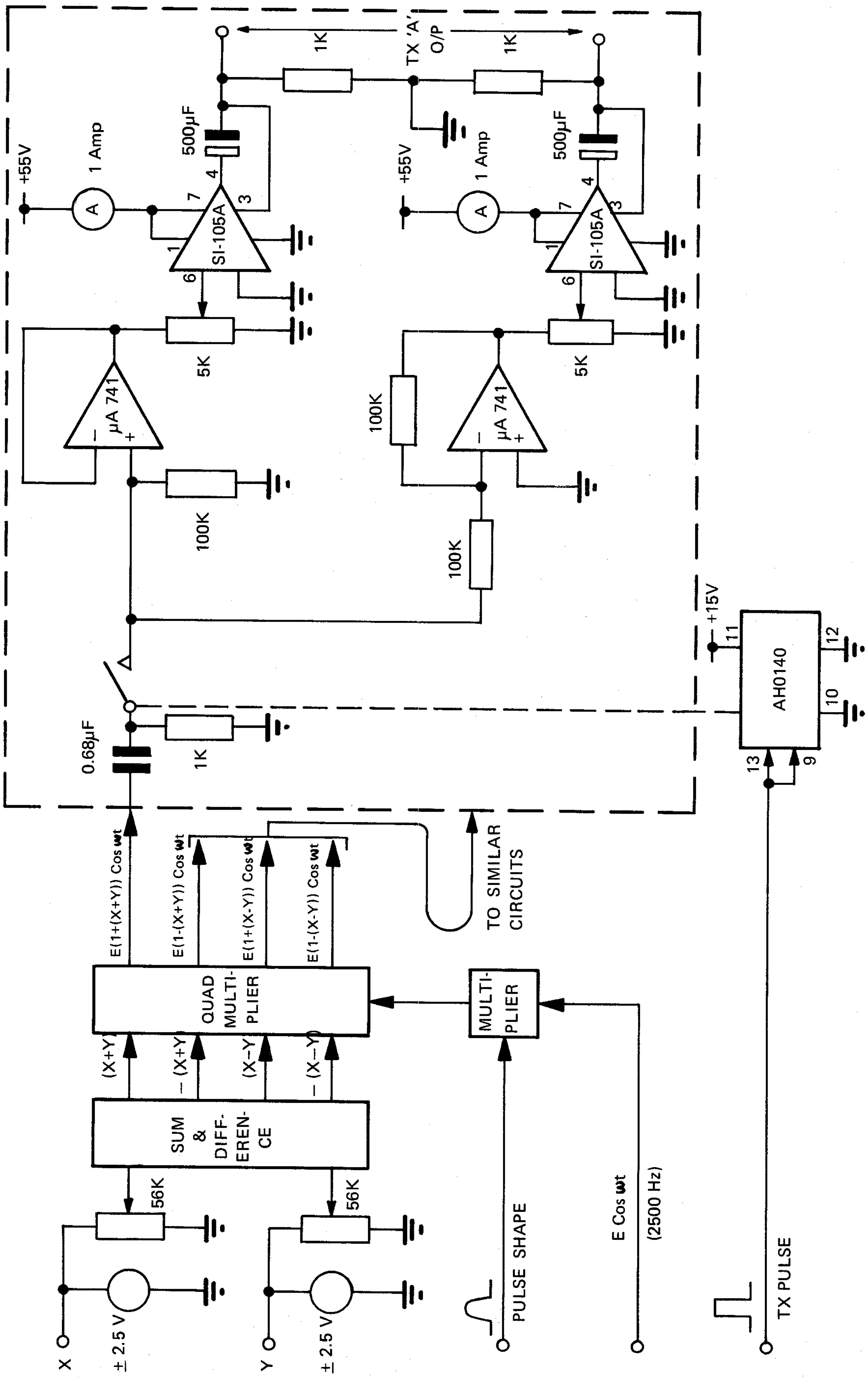


Figure 14. Transmitter circuit

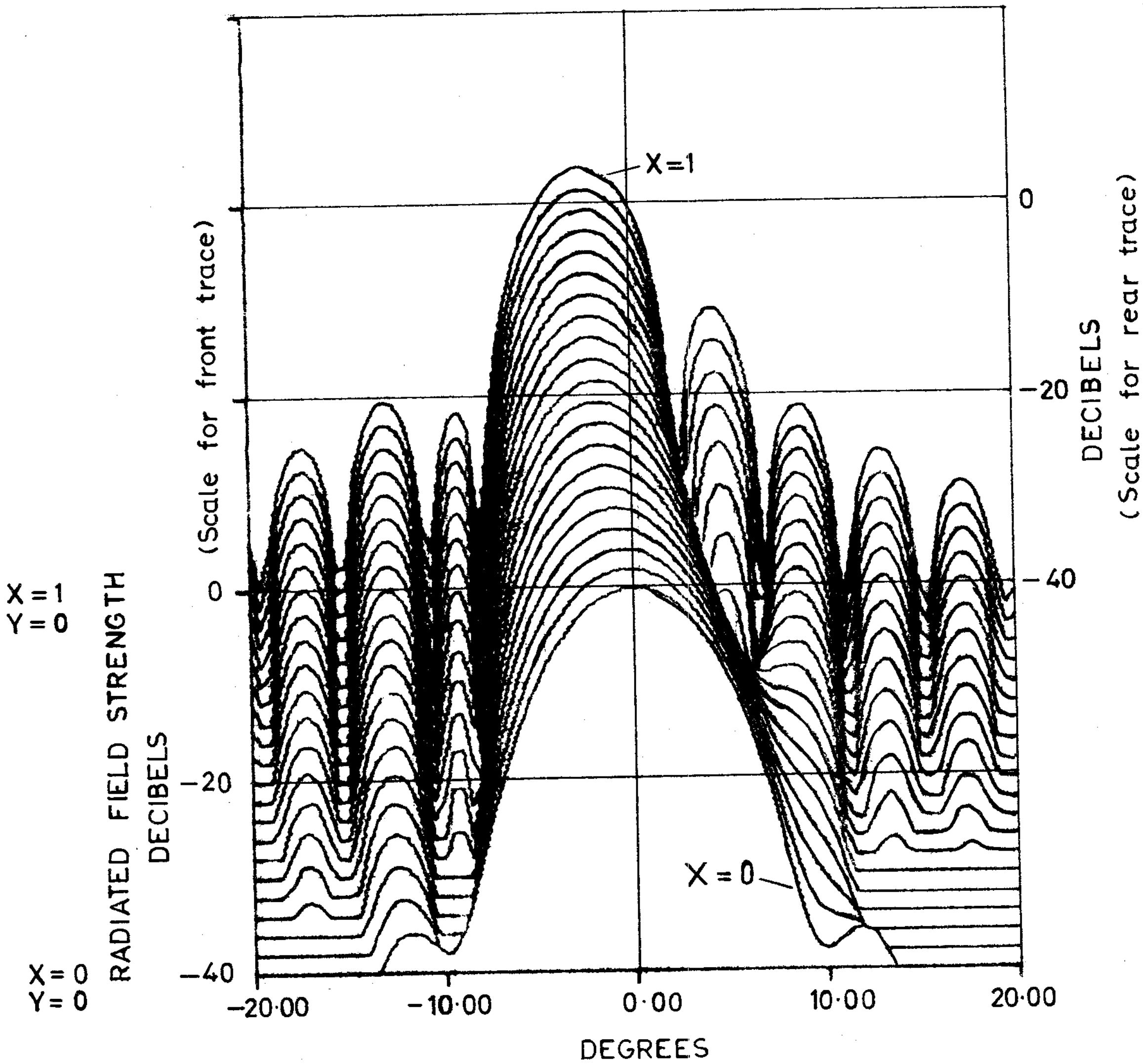


Figure 15. Deflection of antenna field pattern as X is varied from 0 to 1 while Y = 0. (Traces show successive increments in X of 0.05)

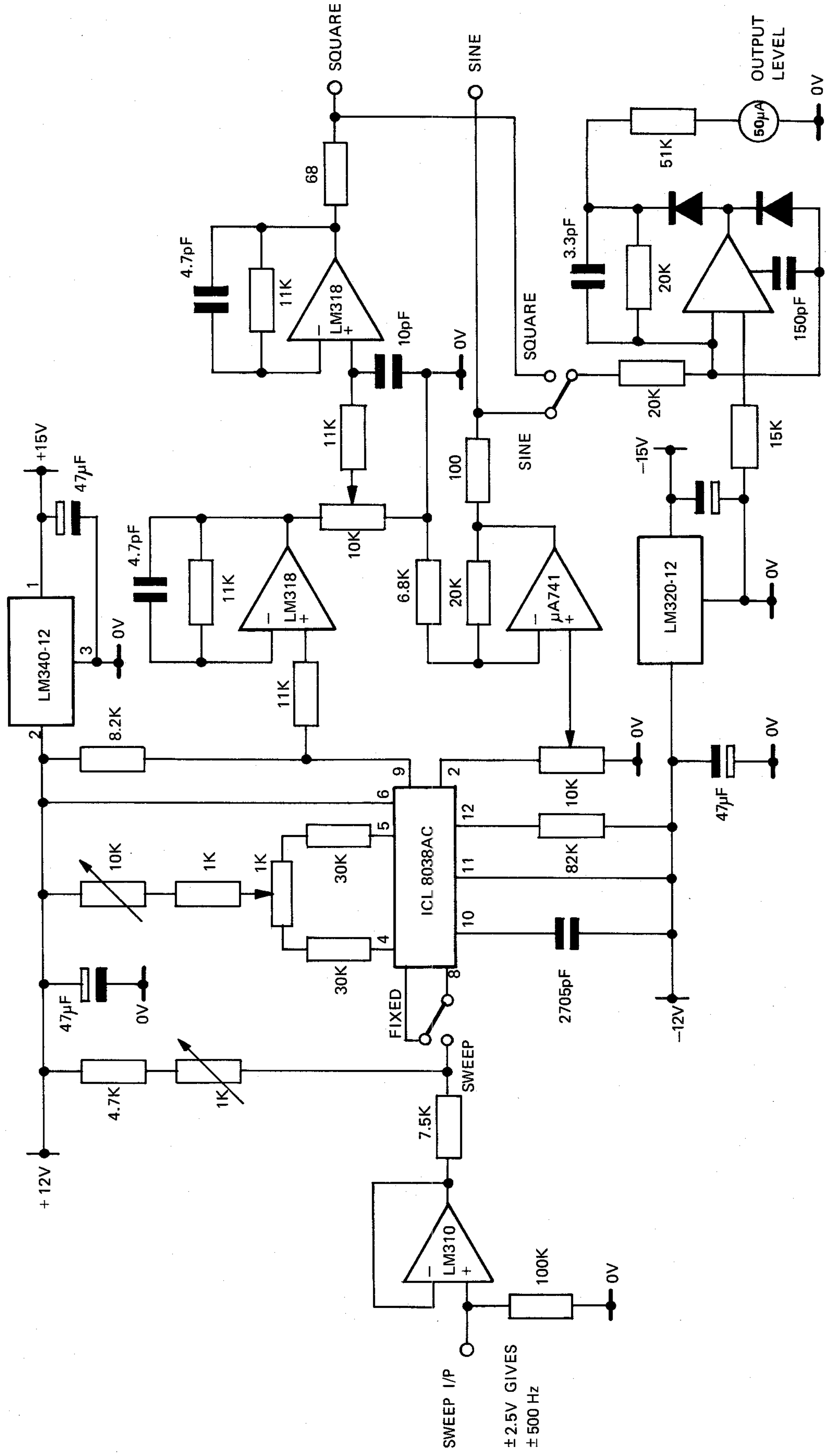


Figure 16. 2500 Hz signal source circuit

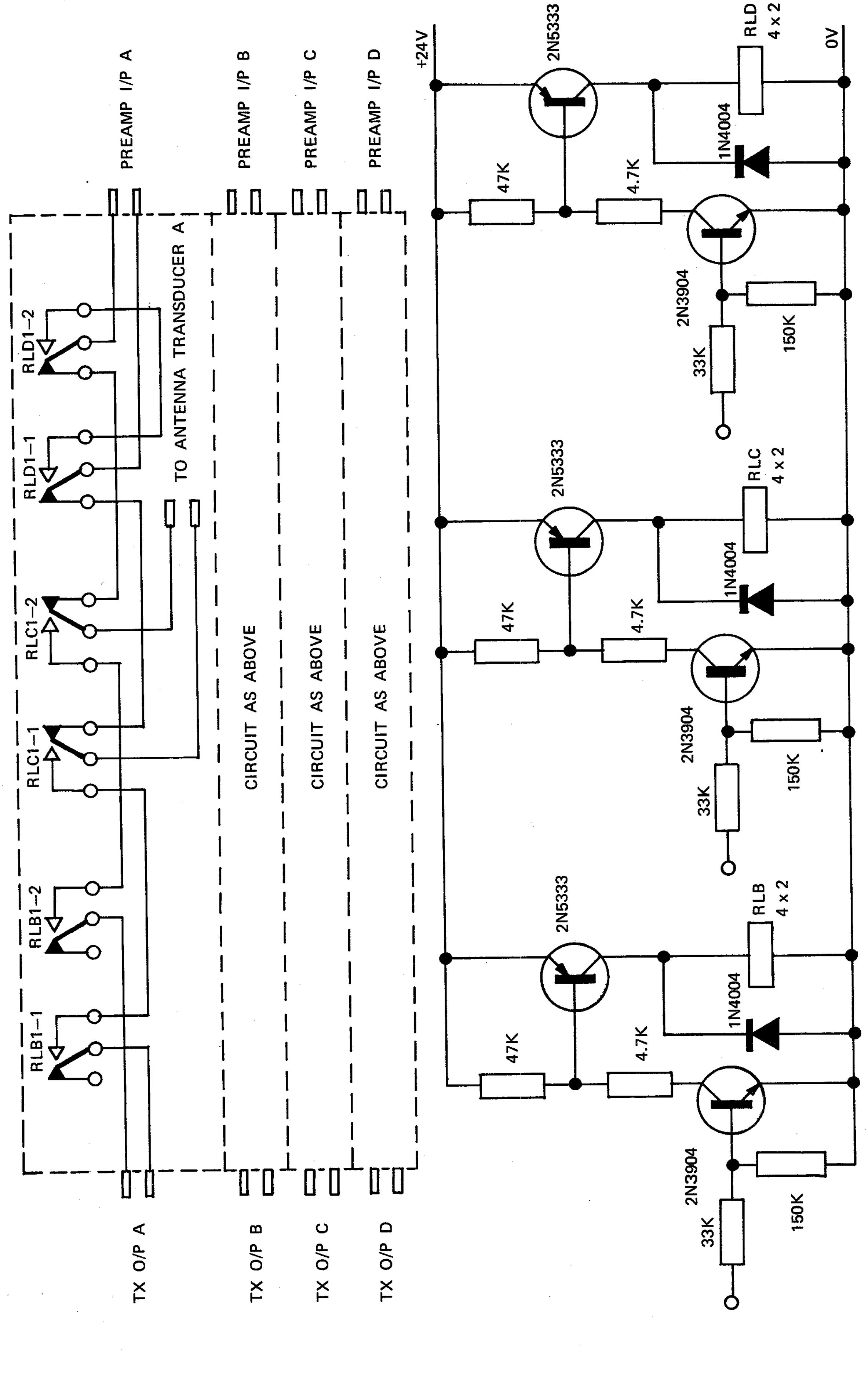


Figure 17. Transmit/Receive changeover unit

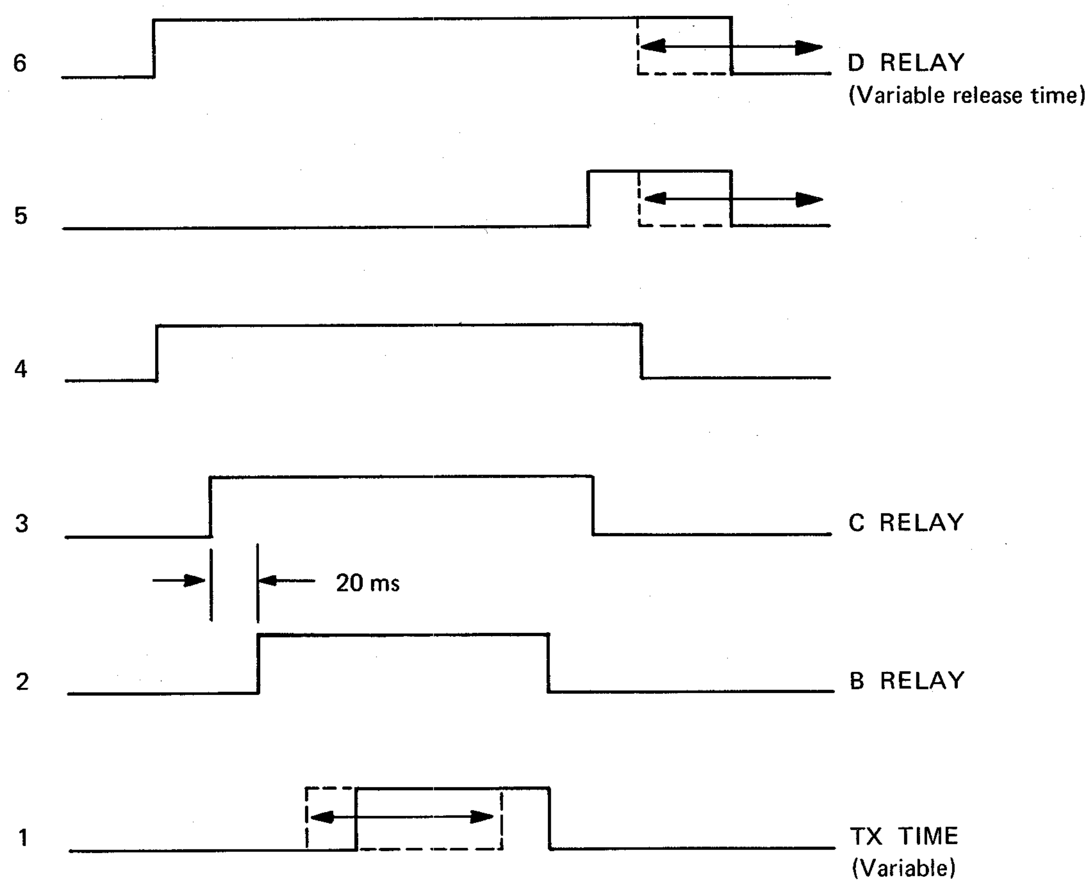


Figure 18. Transmit/Receive unit relay timing

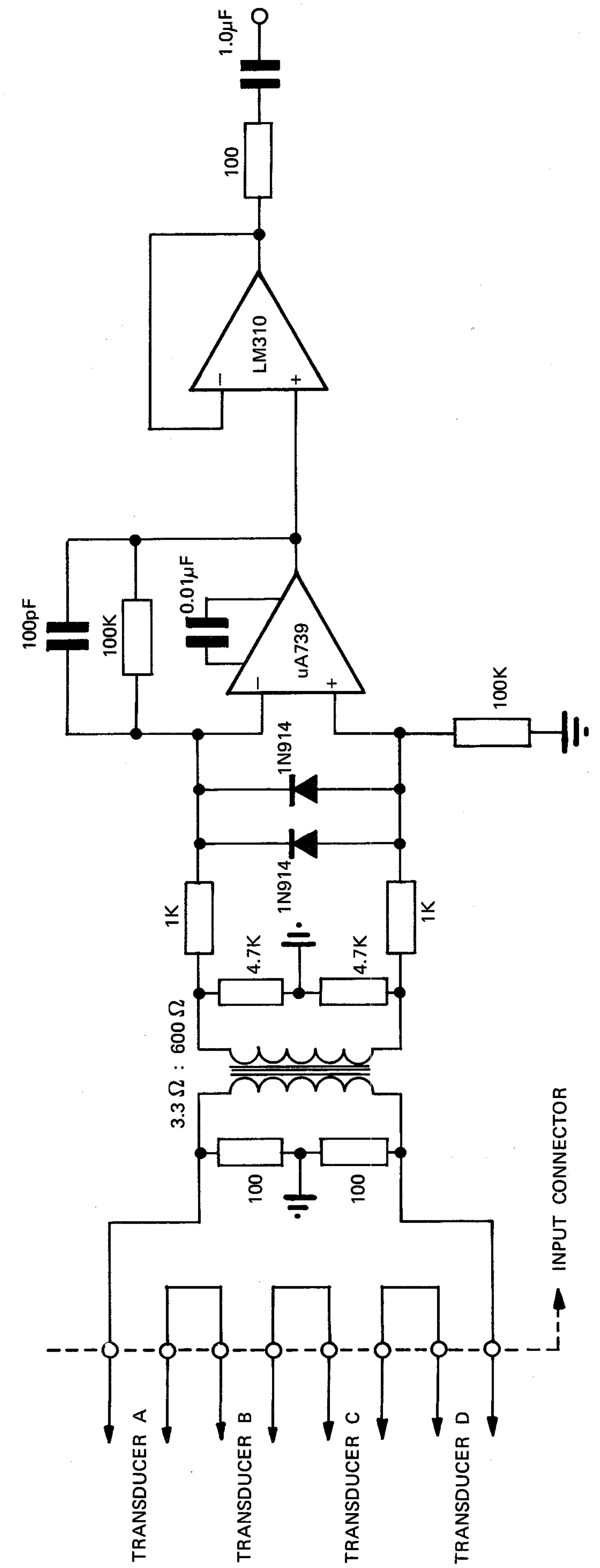


Figure 19. Doppler preamplifier circuit

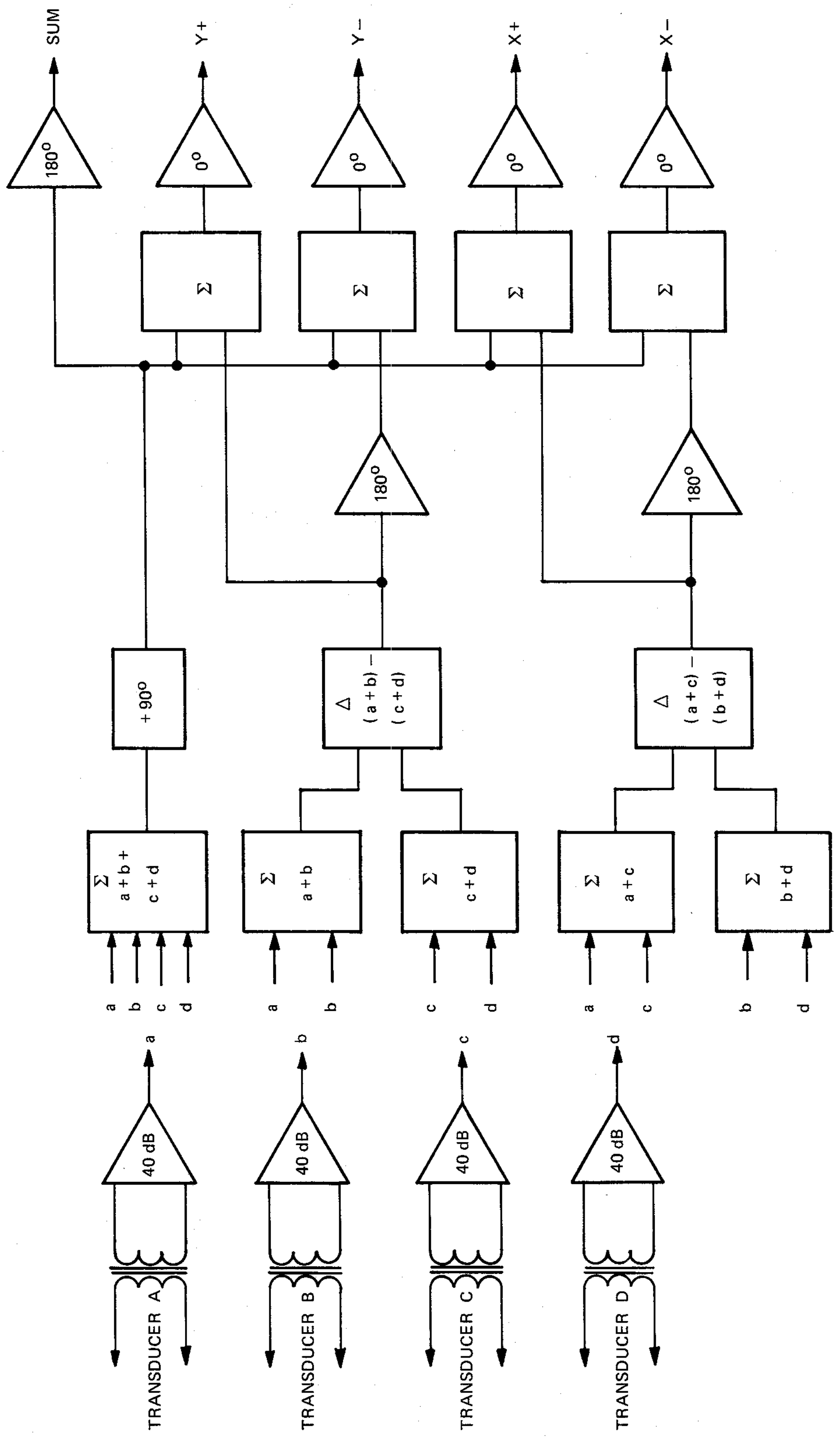


Figure 20. Signal processing in angle-of-arrival preamplifier

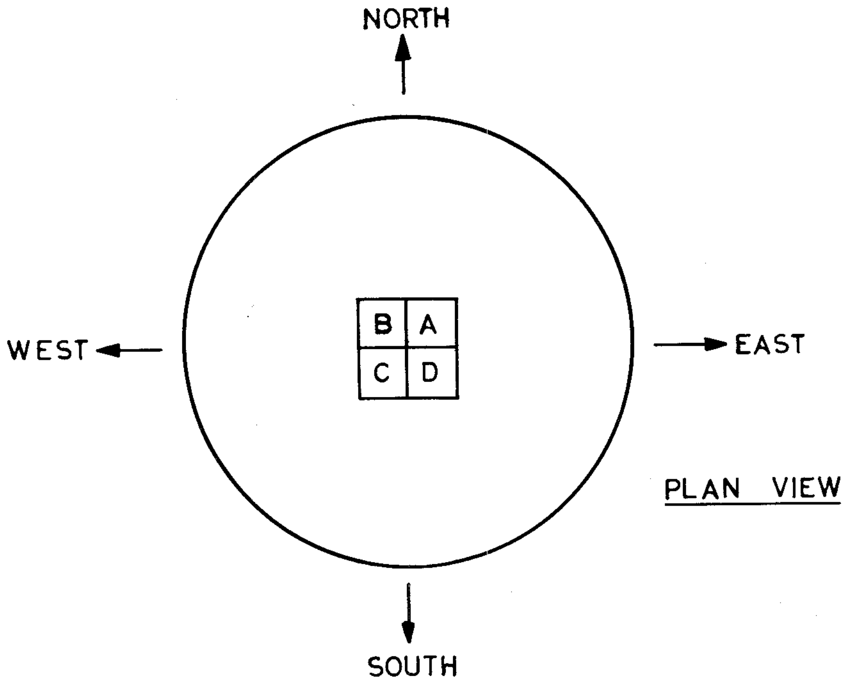


Figure 21. Layout of transducers in antenna

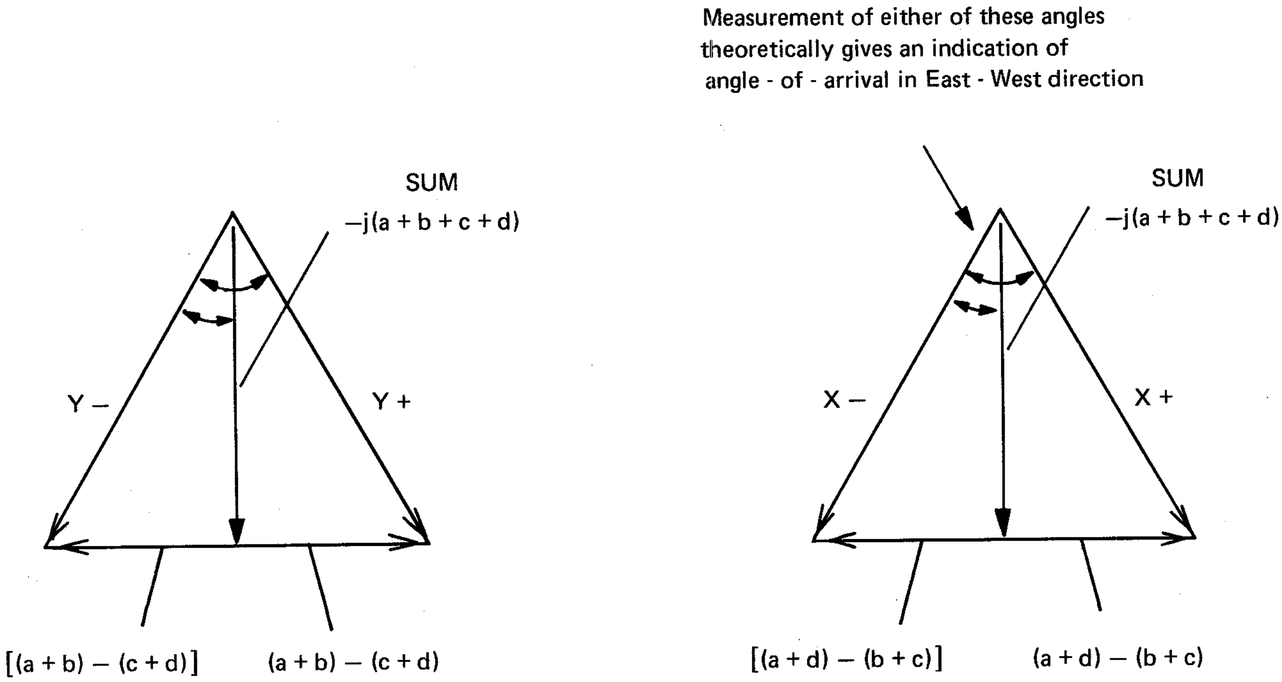


Figure 22. Phase relationships between outputs of the angle-of-arrival preamplifier

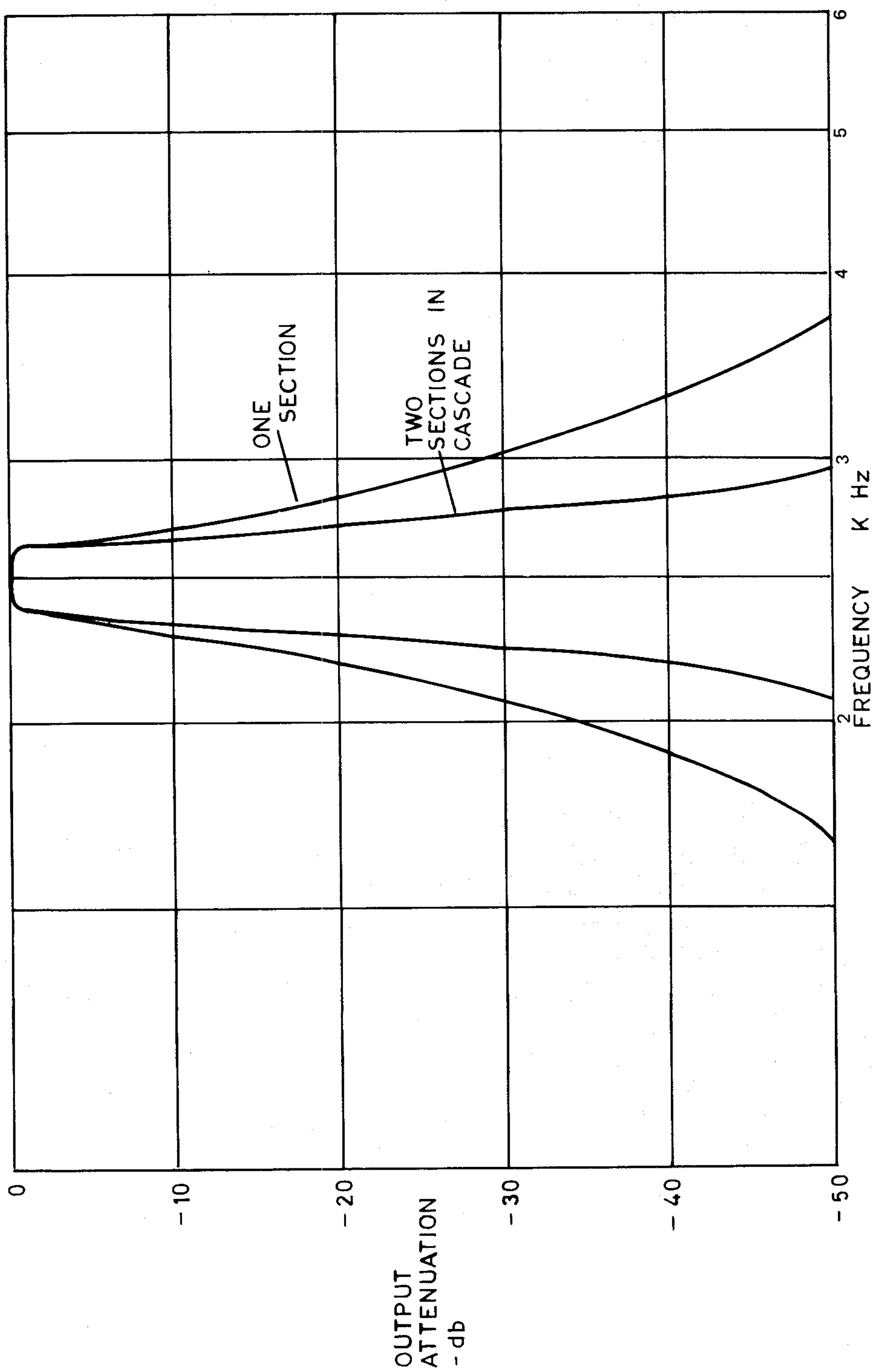


Figure 23. Bandpass amplifier frequency response

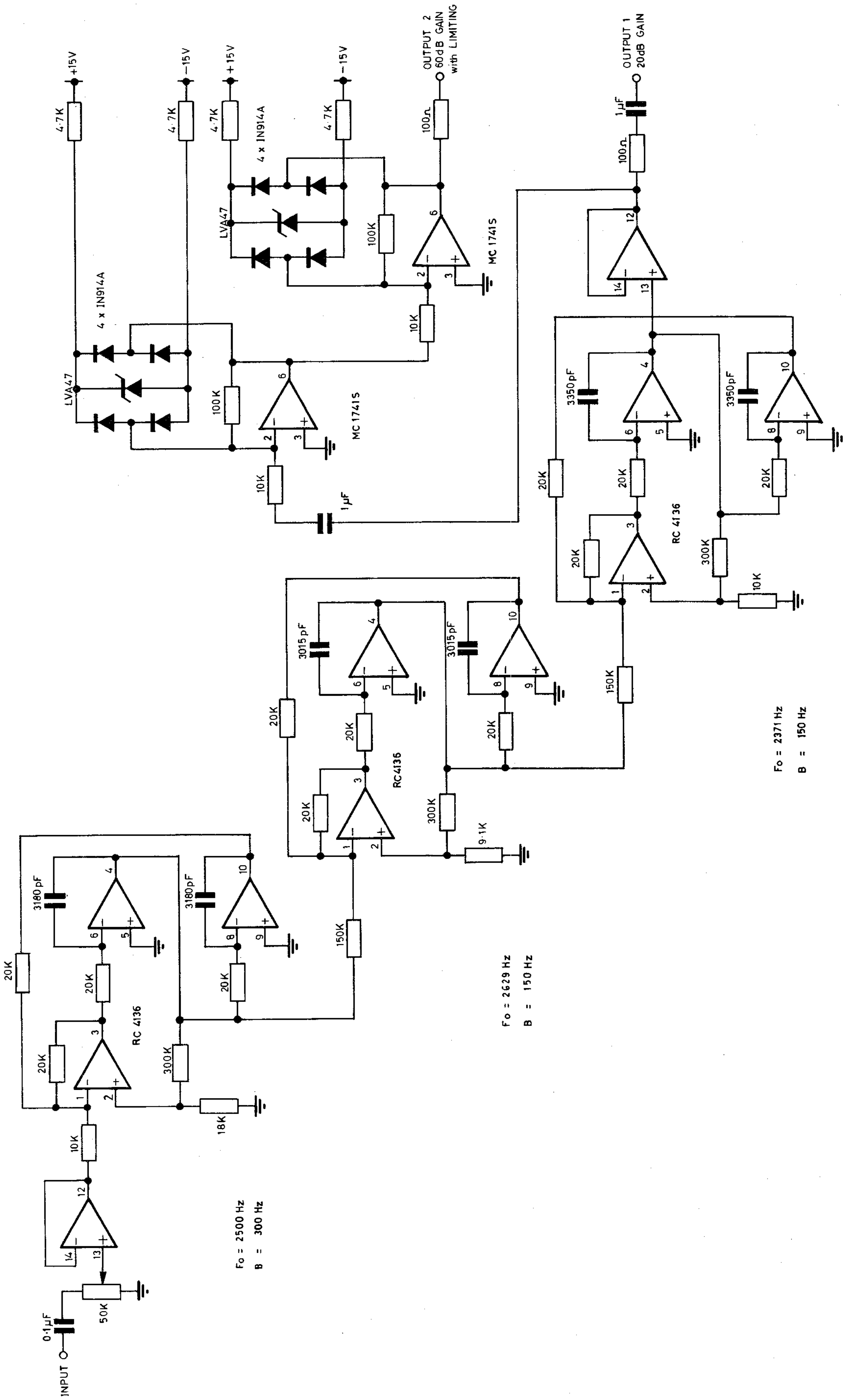
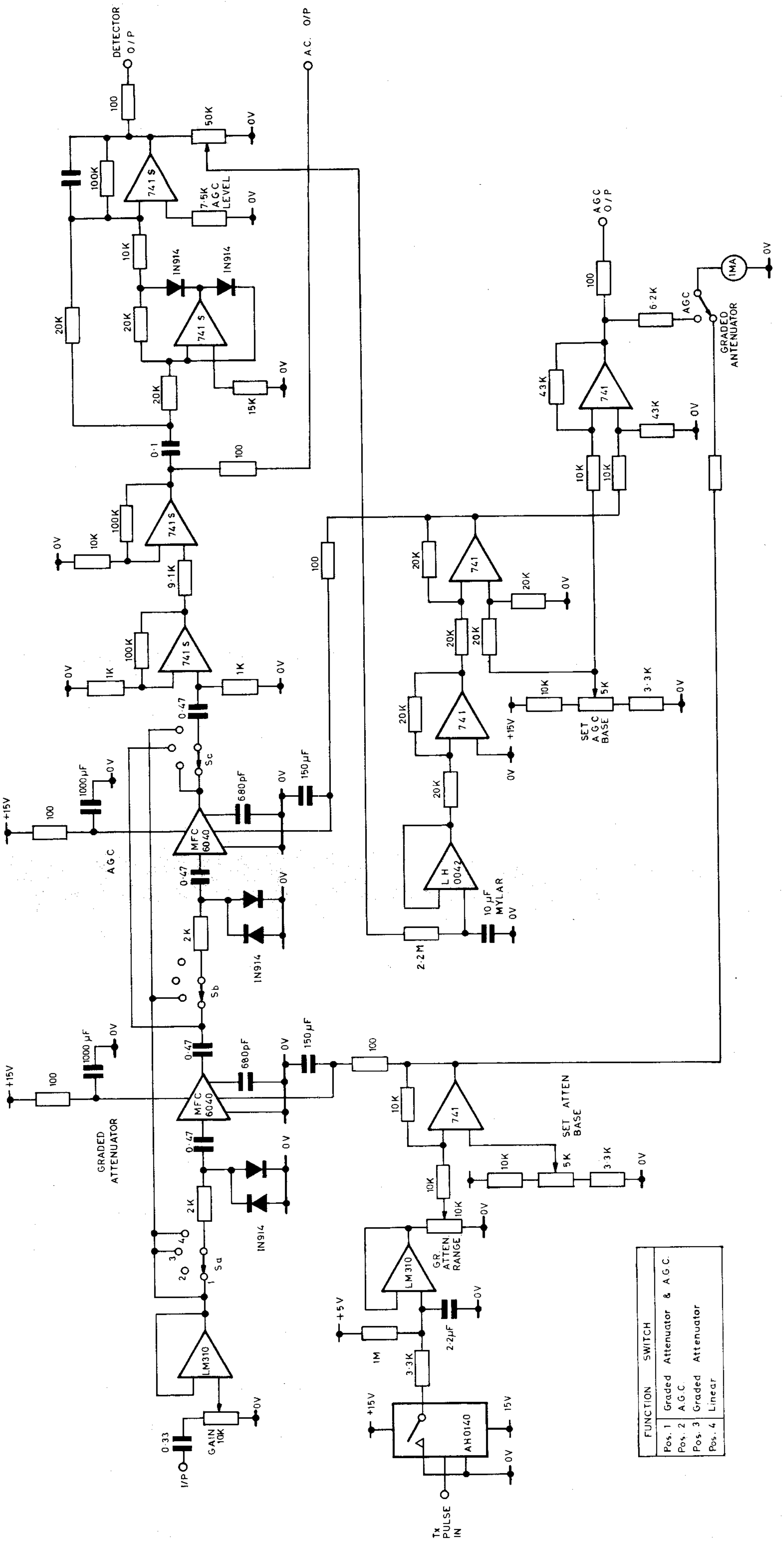


Figure 24. Bandpass amplifier and limiter circuits



FUNCTION	SWITCH
Pos. 1	Graded Attenuator & A.G.C.
Pos. 2	A.G.C.
Pos. 3	Graded Attenuator
Pos. 4	Linear

Figure 25. Amplitude receiver circuit

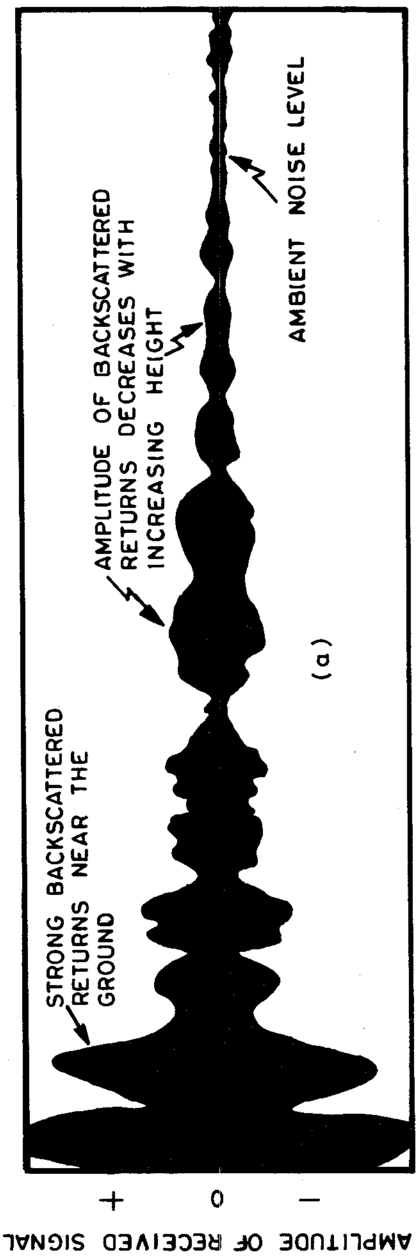


Figure 26. Typical monostatic acoustic return

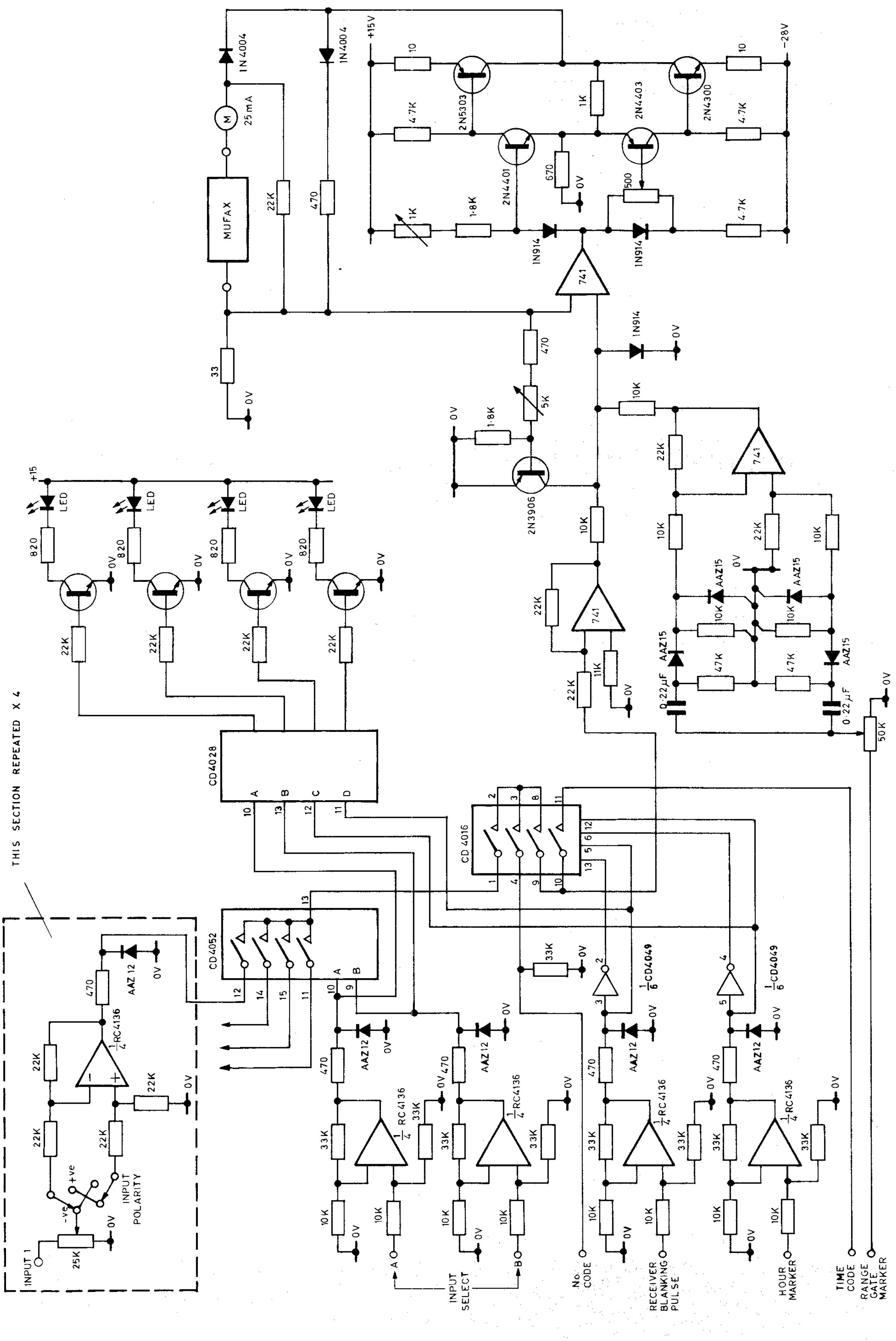


Figure 27. Facsimile recorder write amplifier circuit

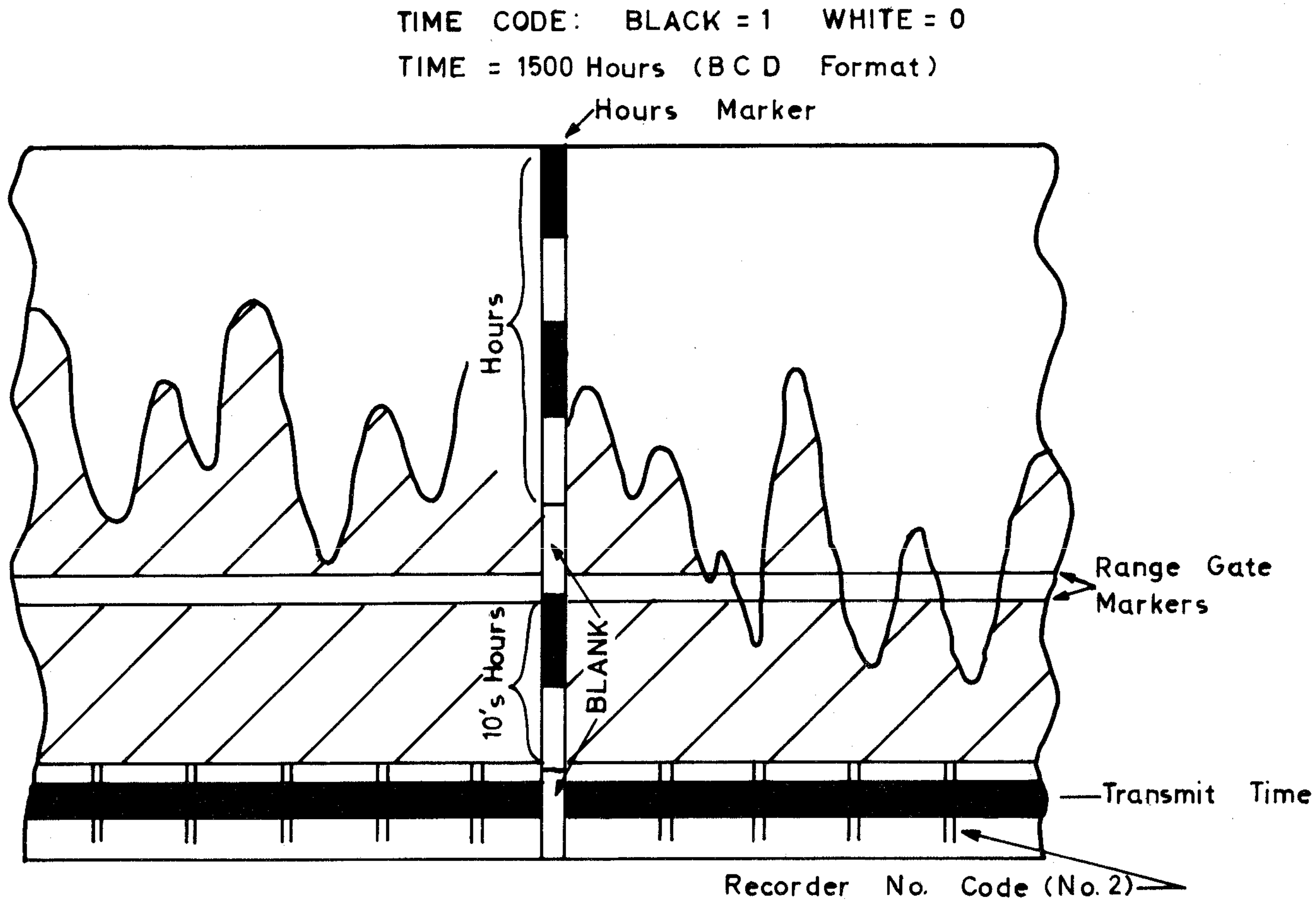


Figure 28. Timing and identification markers placed on facsimile records

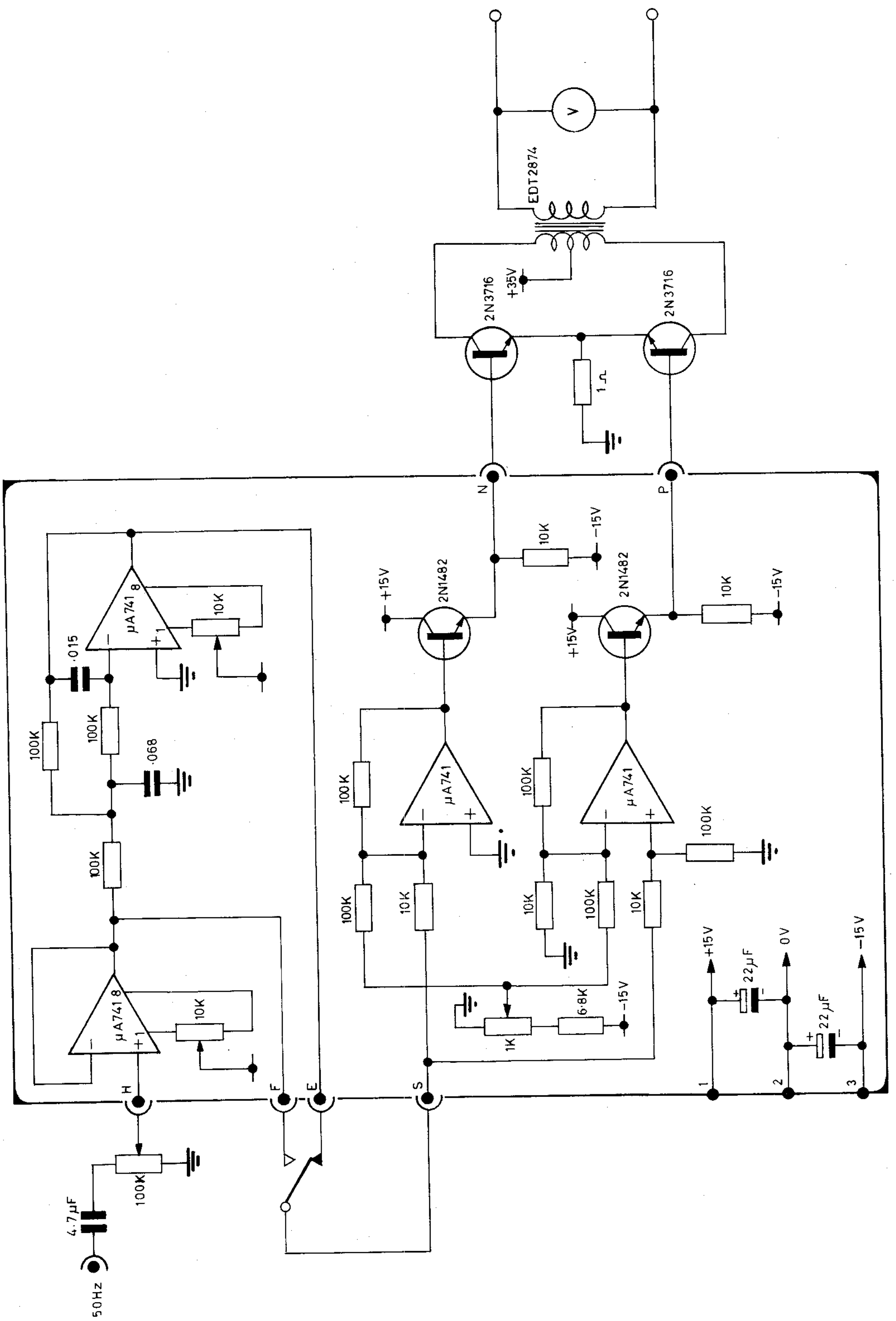


Figure 29. Facsimile recorder drive amplifier circuit

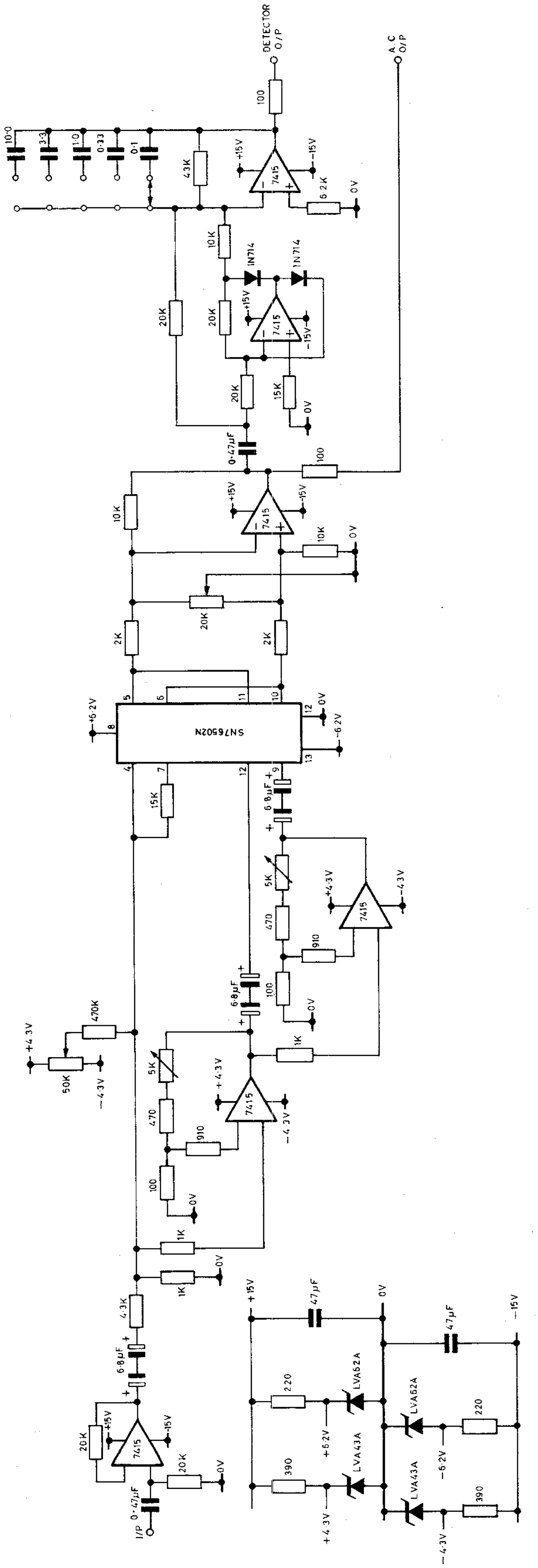


Figure 30. Logarithmic amplifier circuit

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Figure 31

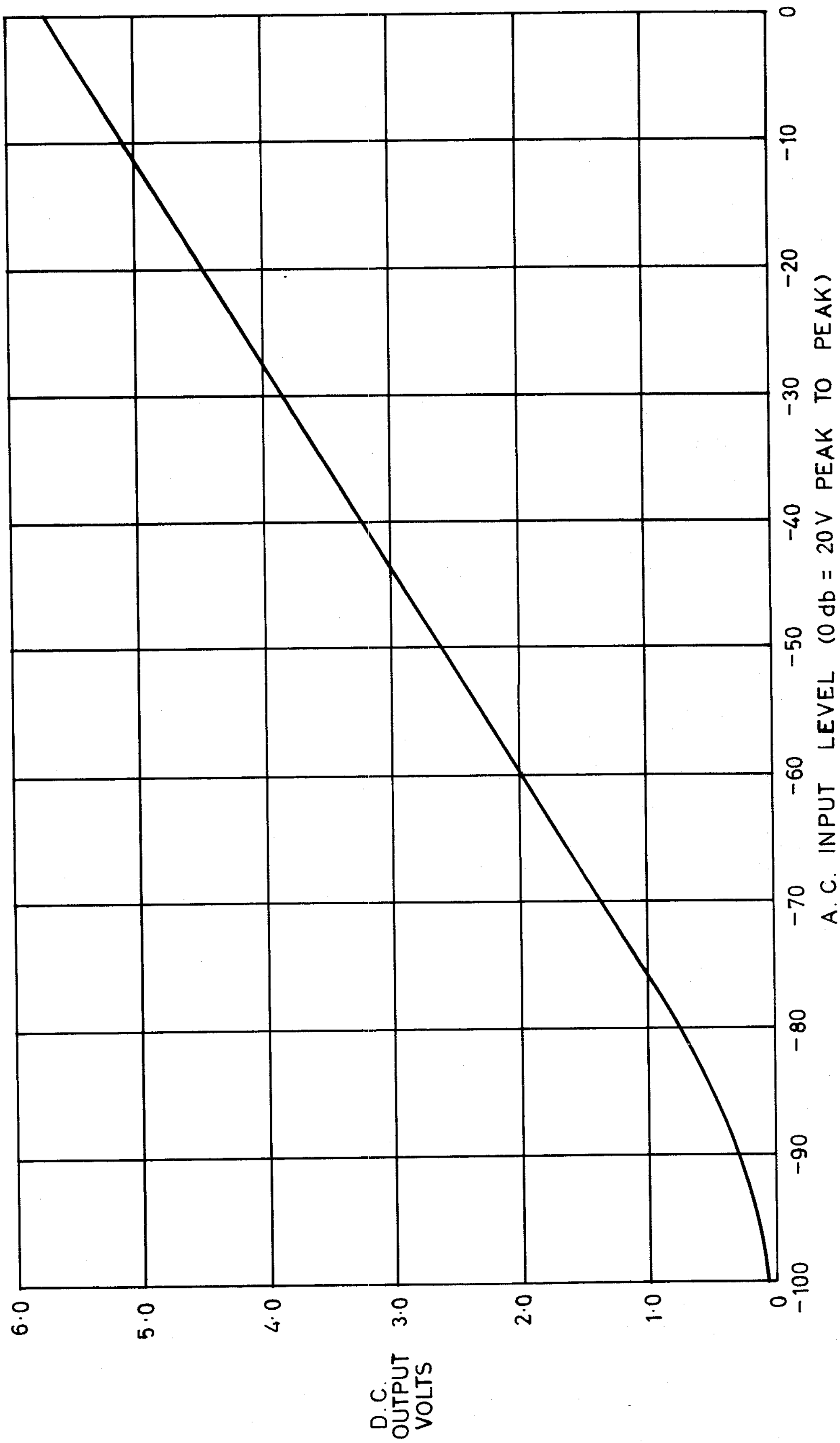


Figure 31. Logarithmic amplifier response

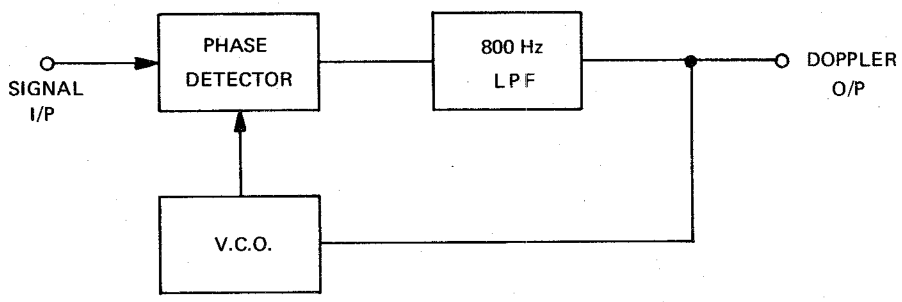


Figure 32. First-order tracking filter.

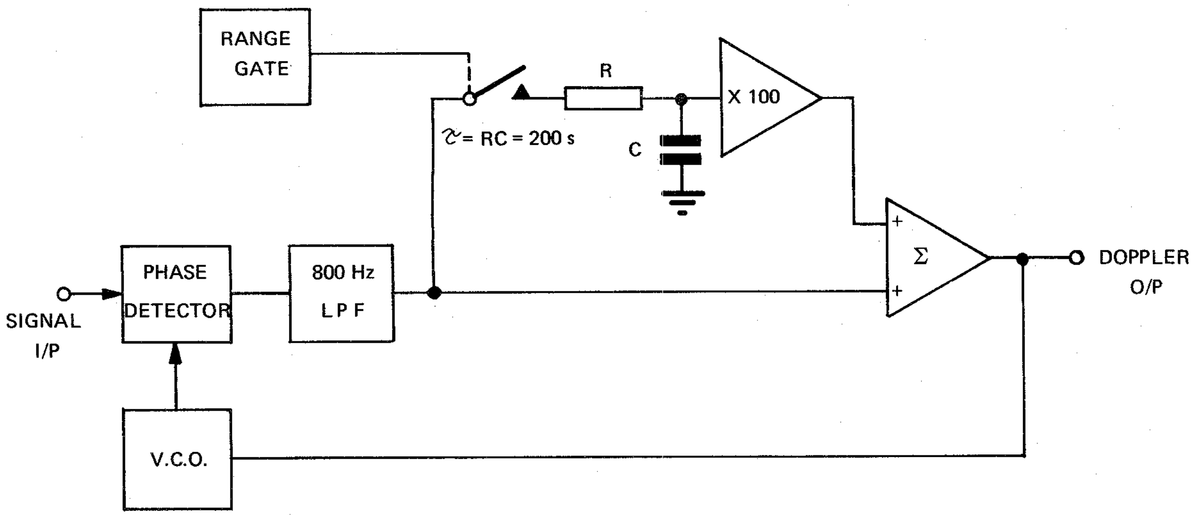


Figure 33. First-order tracking filter with range-gated integrator.

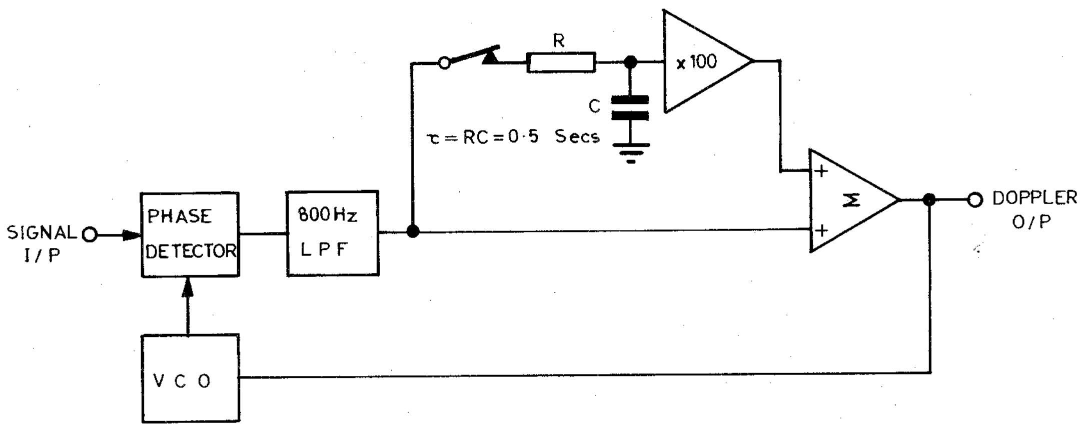


Figure 34. Second-order tracking filter.

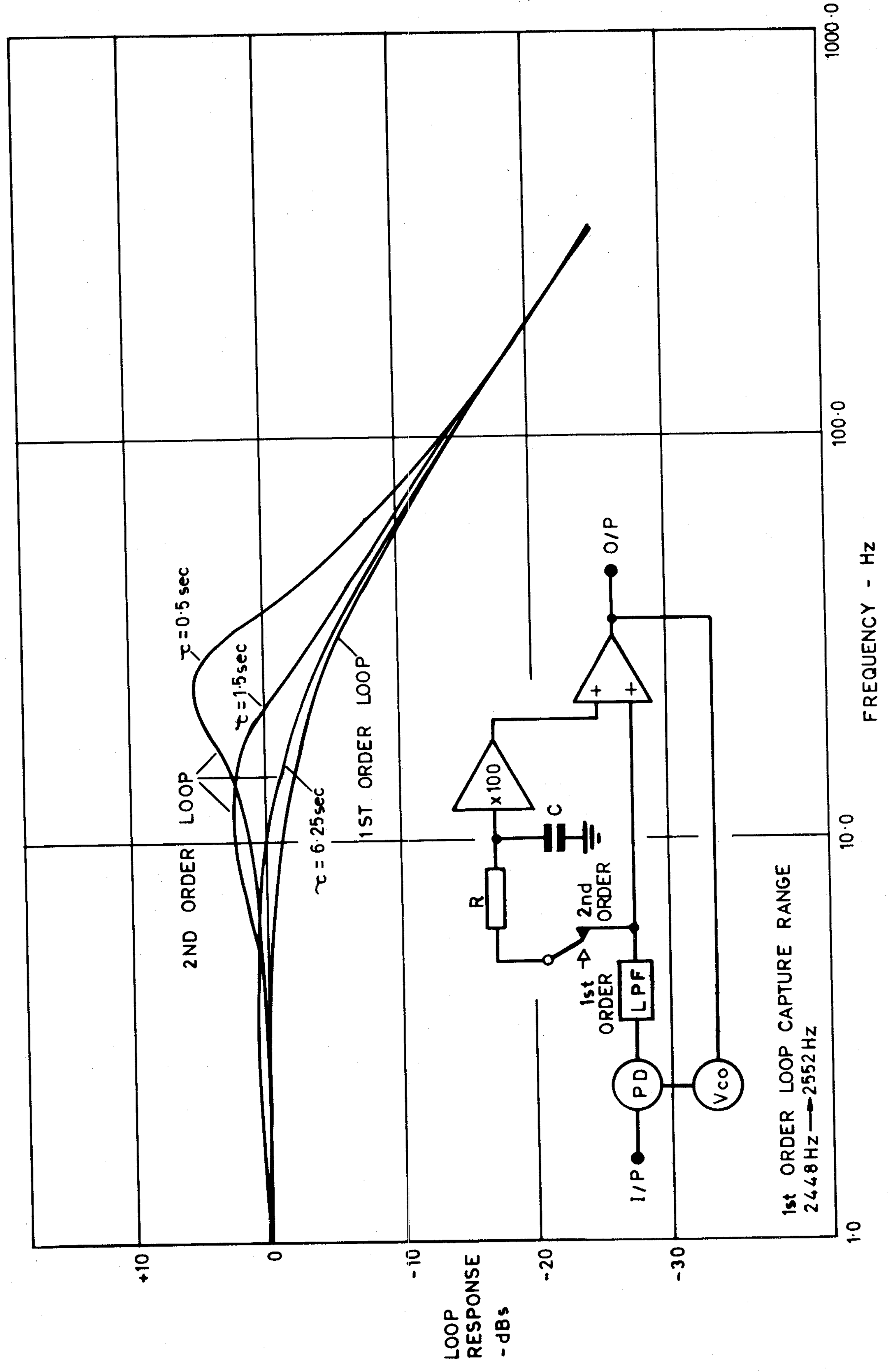


Figure 35. Tracking filter loop response

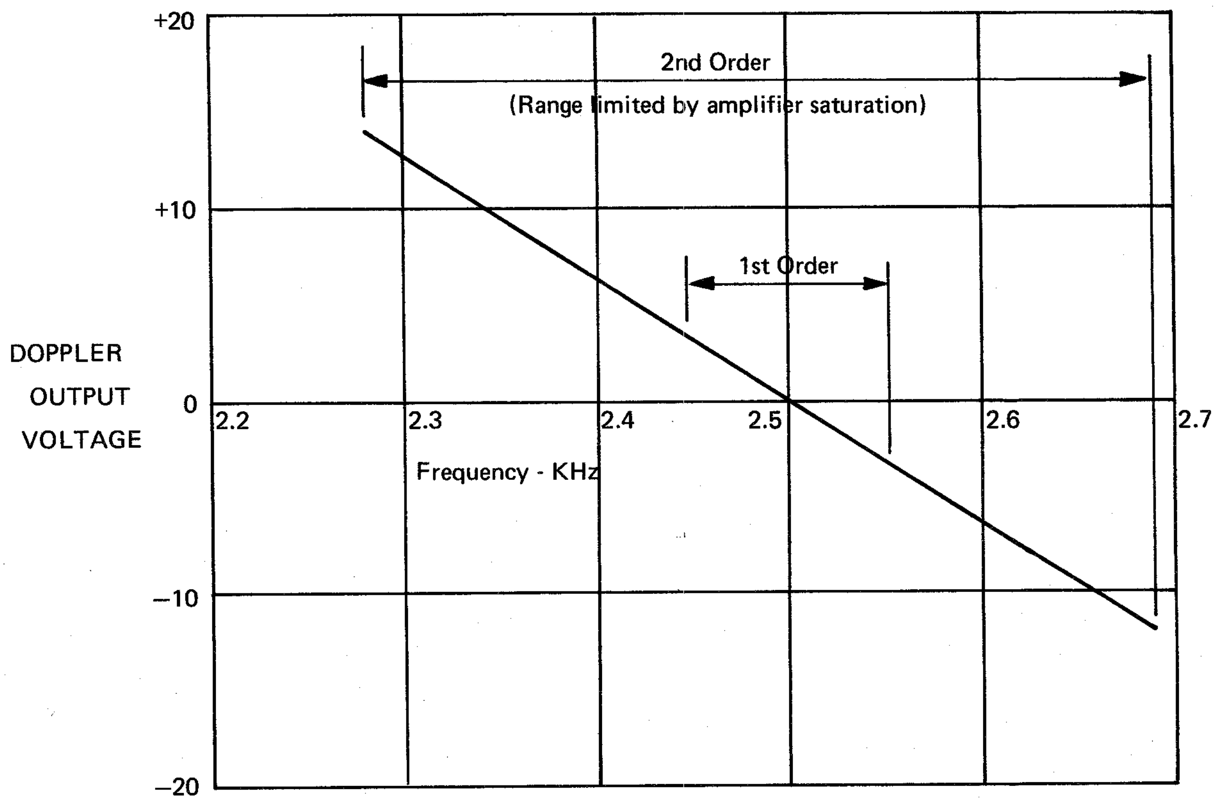


Figure 36. Range and output sensitivity of first and second order tracking filters

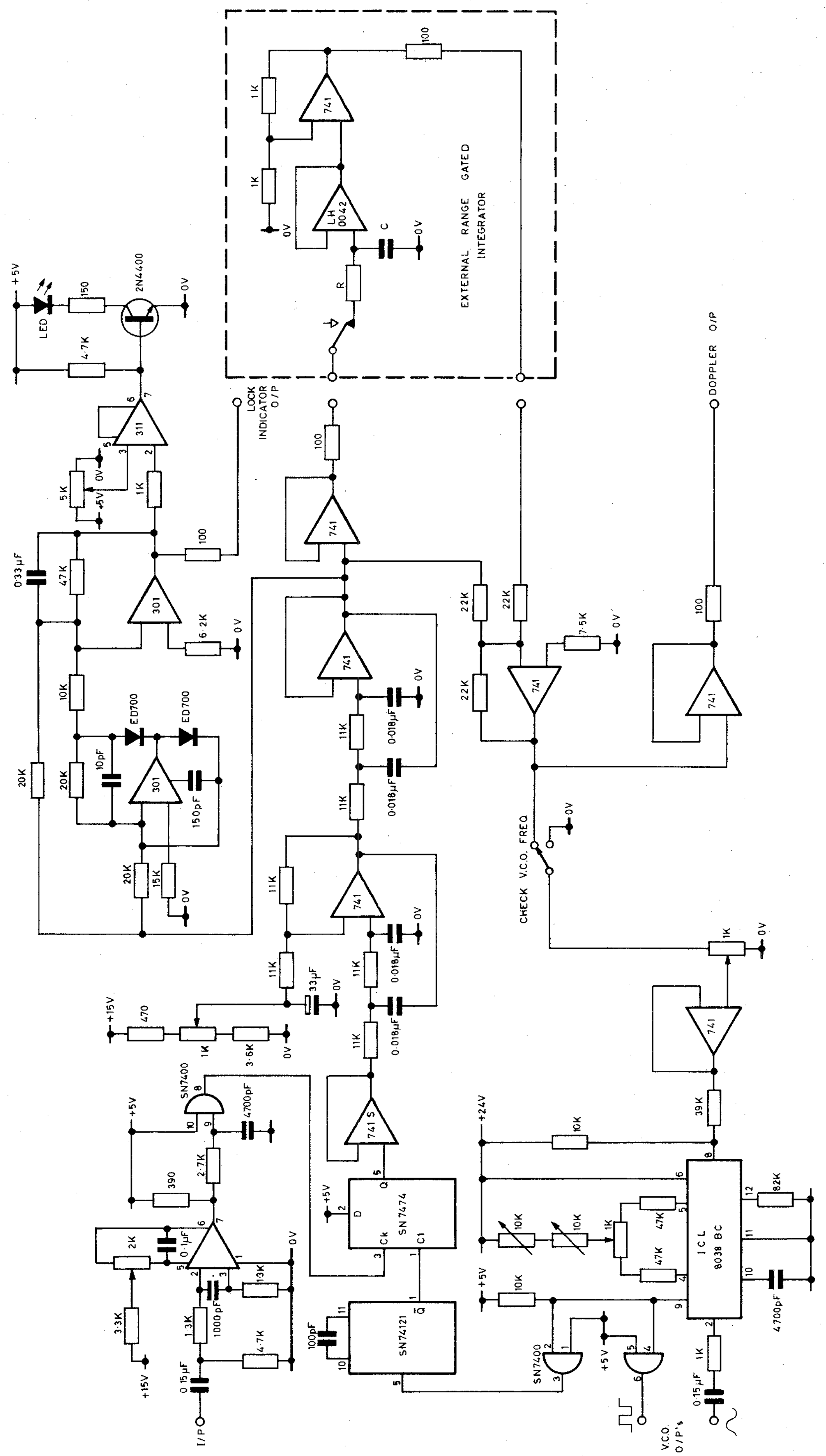
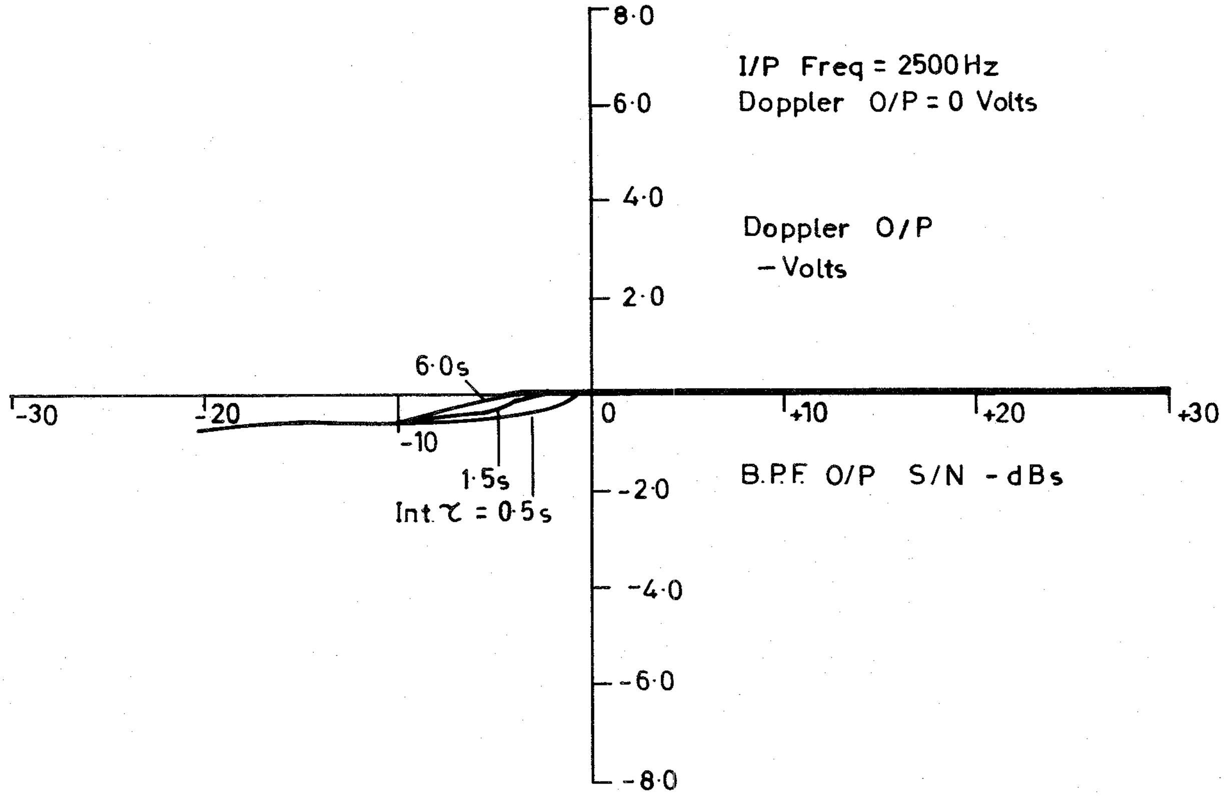


Figure 37. Basic circuit of doppler-tracking filter



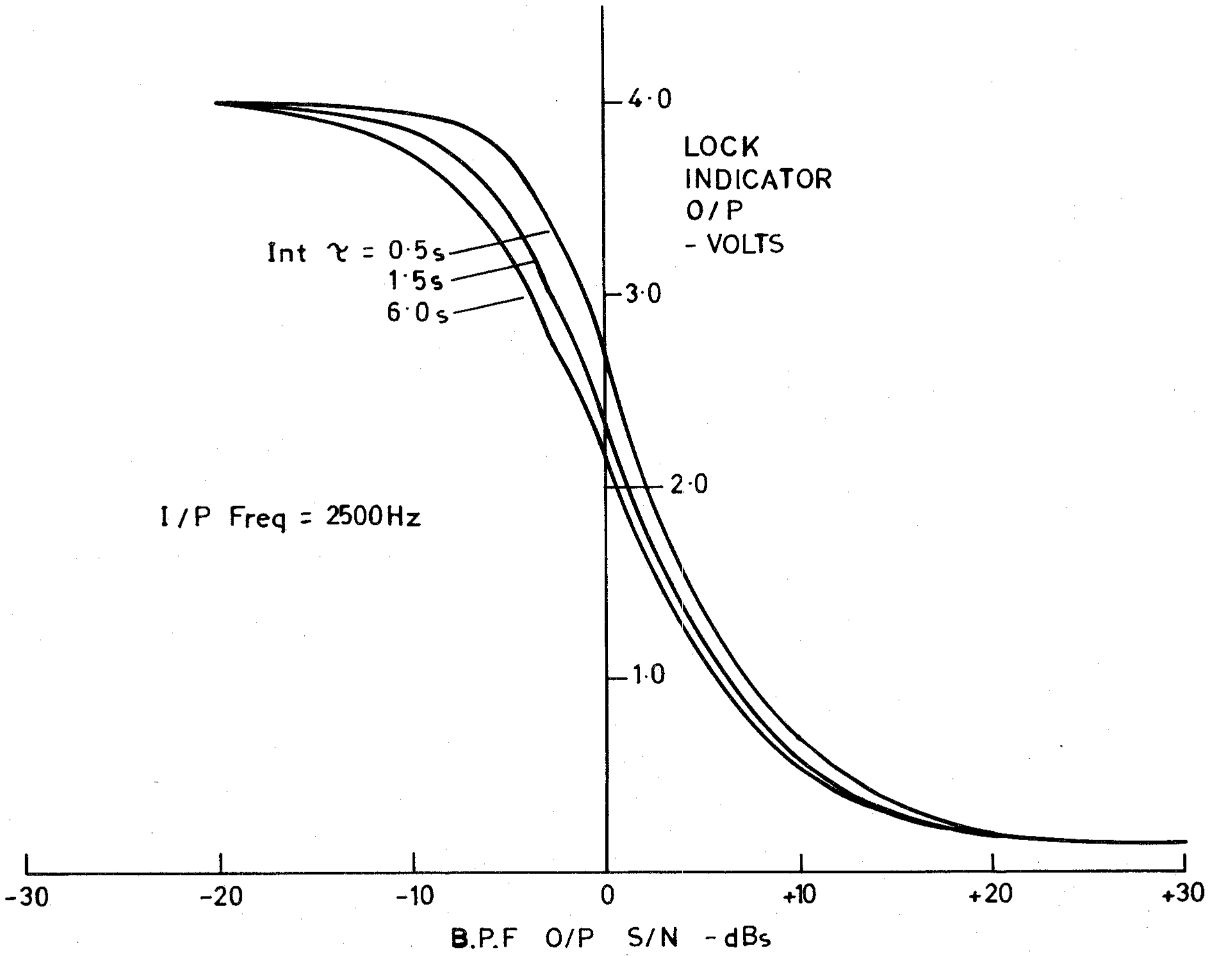


Figure 38(a). Doppler and lock indicator S/N responses at 2500 Hz

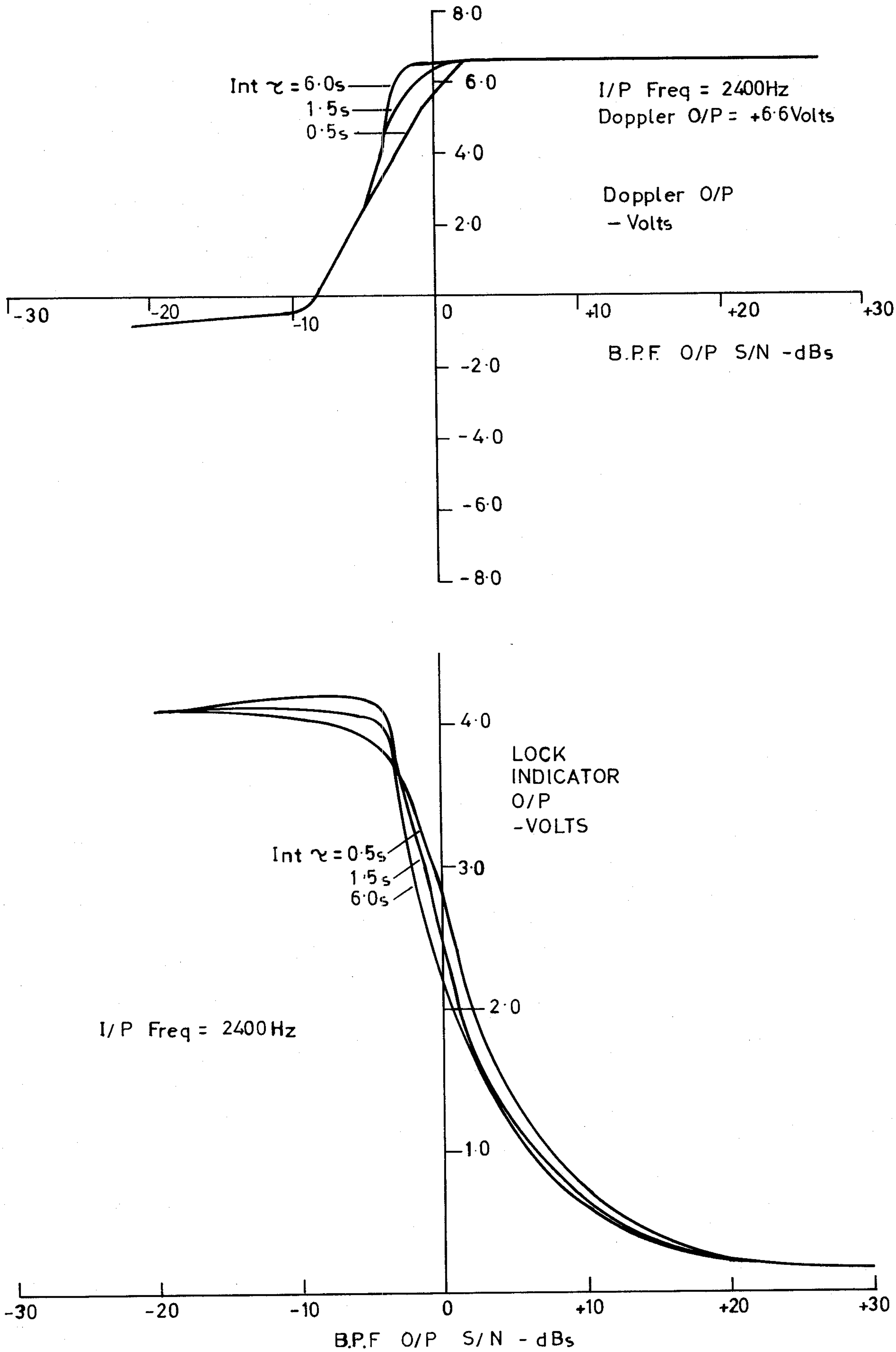


Figure 38(b). Doppler and lock indicator S/N responses at 2400 Hz

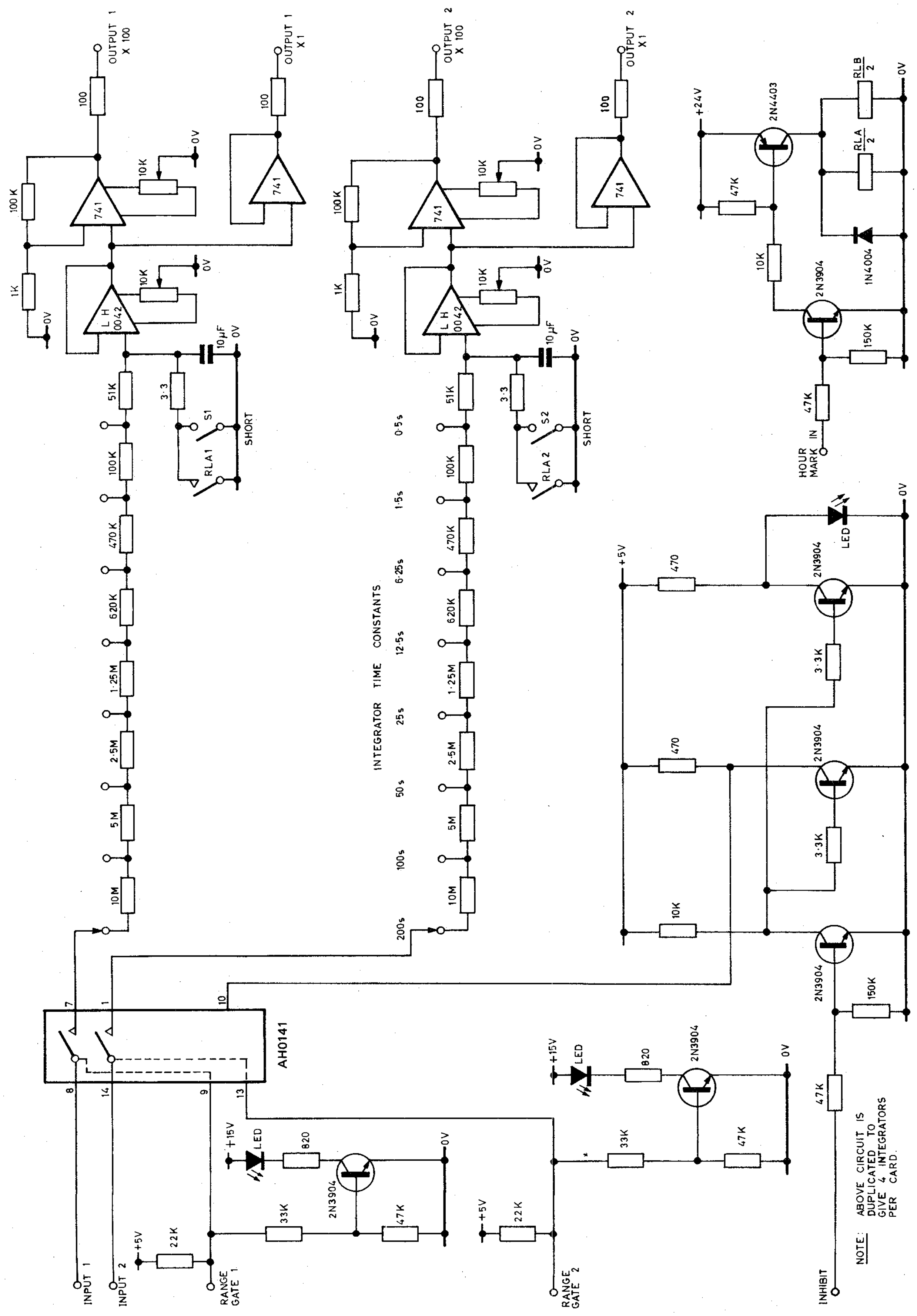
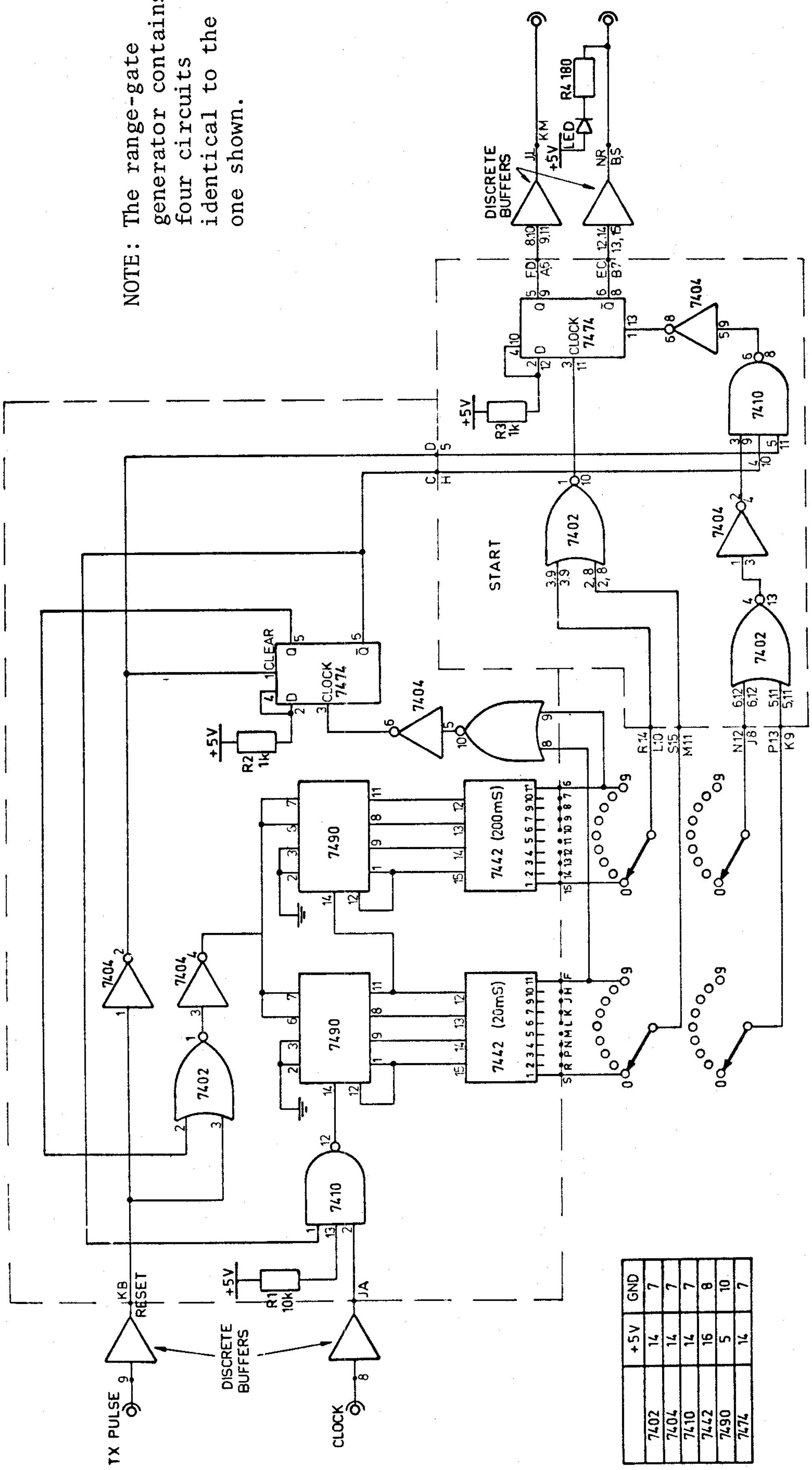


Figure 39. Range-gated integrator circuit

NOTE: The range-gate generator contains four circuits identical to the one shown.



	+5V	GND
7402	14	7
7404	14	7
7410	14	7
7442	16	8
7490	5	10
7474	14	7

Figure 40. Range-gate generator circuit

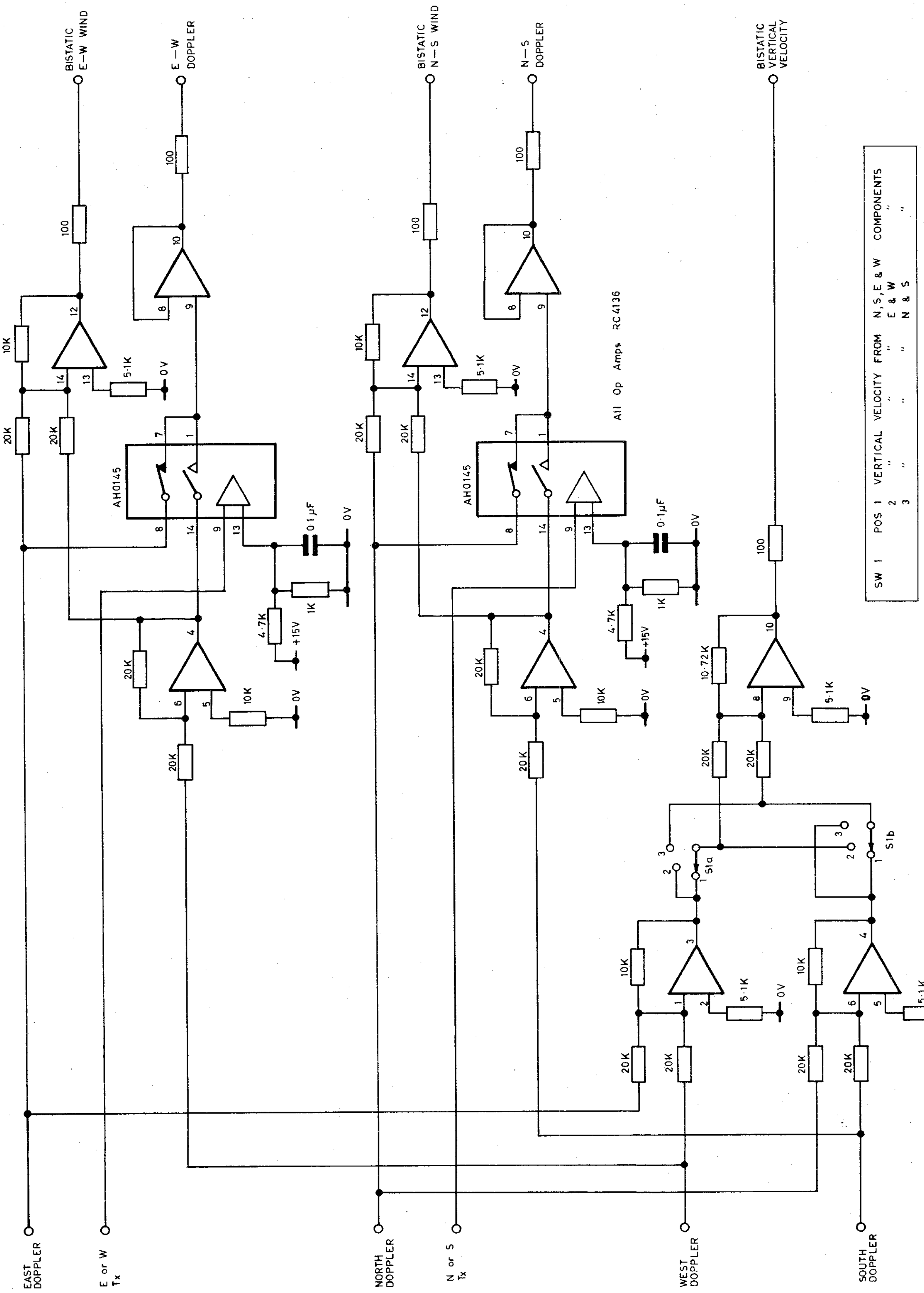


Figure 41(a). Bistatic wind component resolver circuit

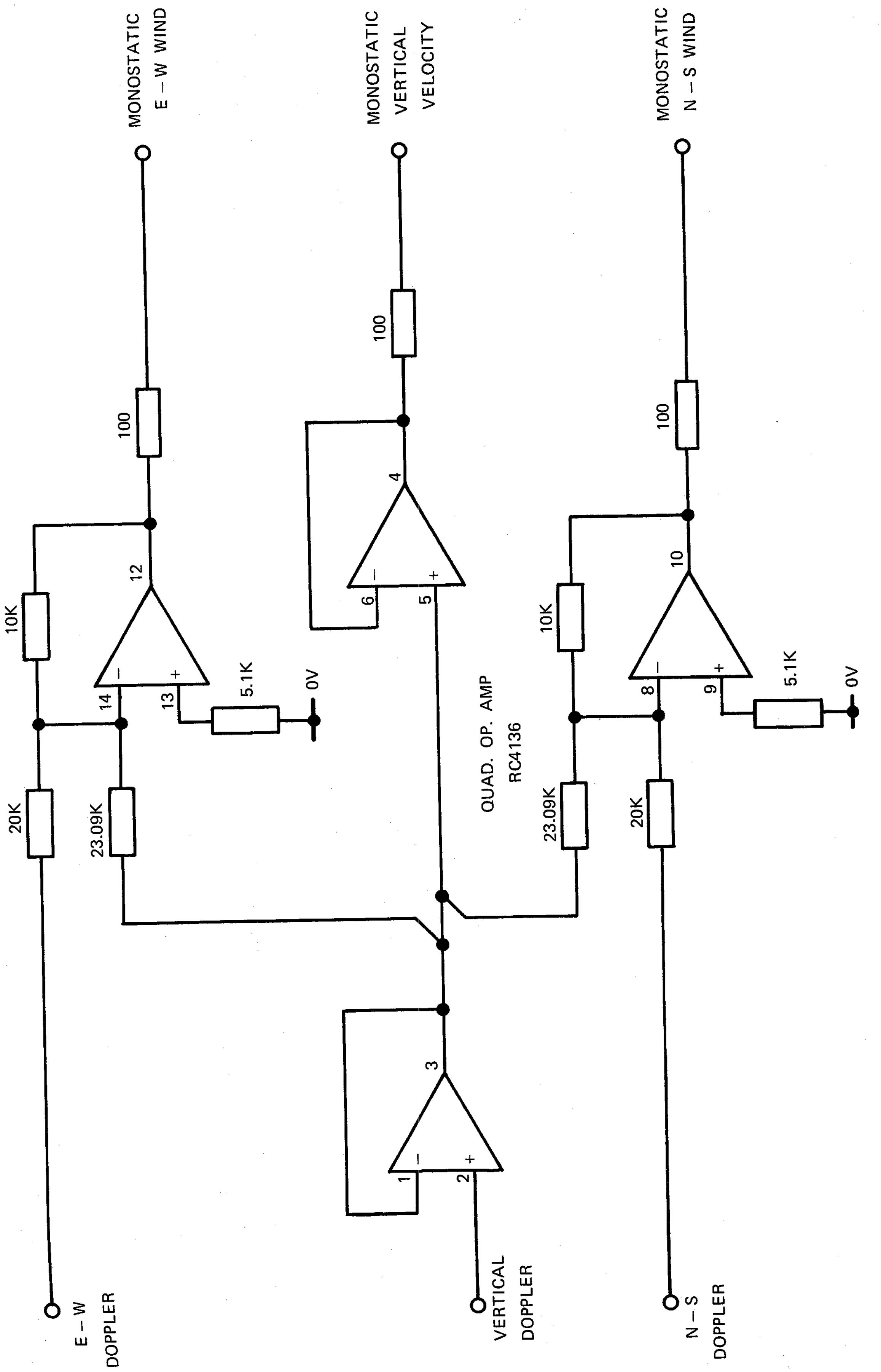


Figure 41(b). Monostatic wind component resolver circuit

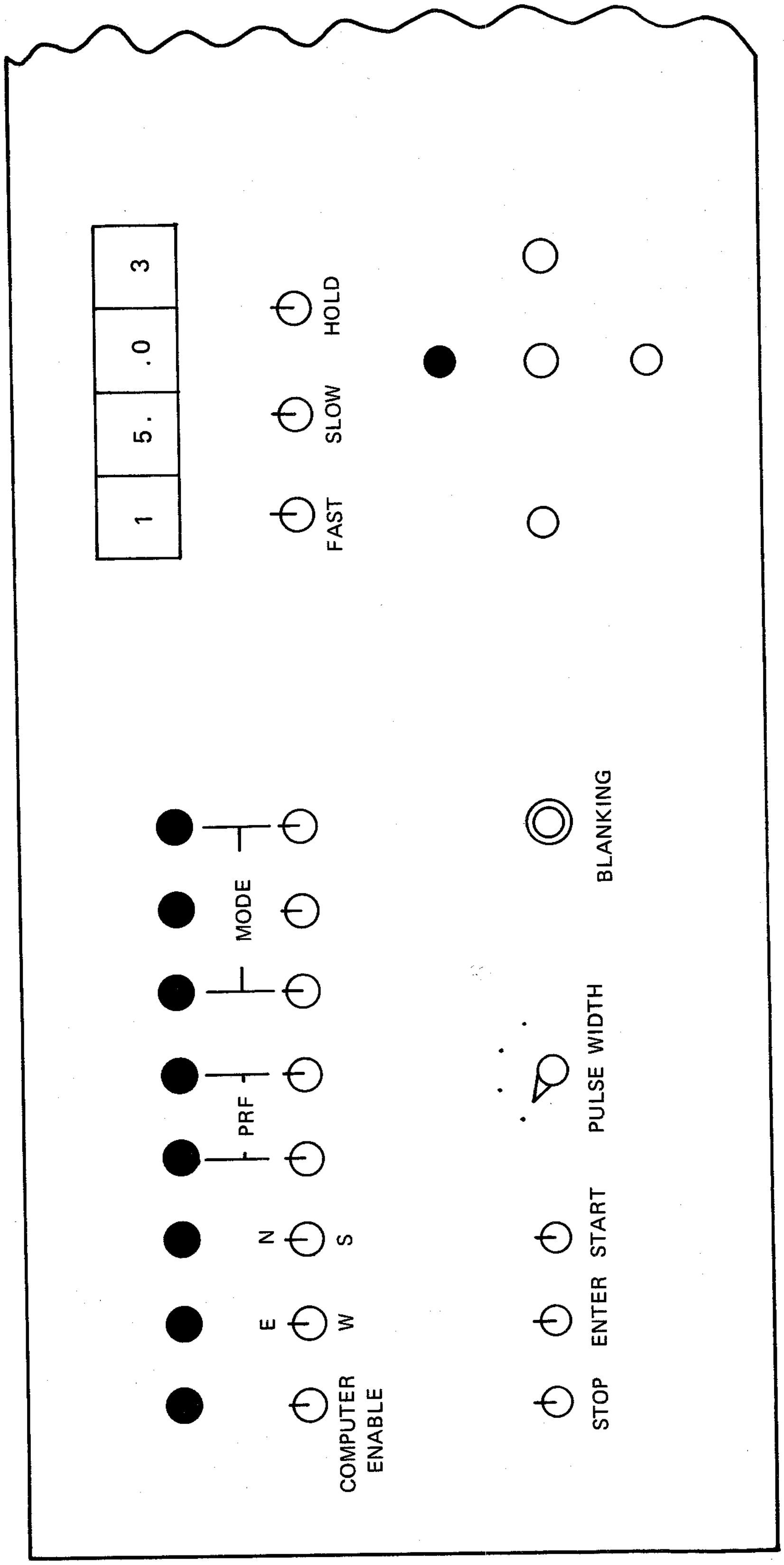


Figure 42. Control panel layout of sequence generator and timing unit

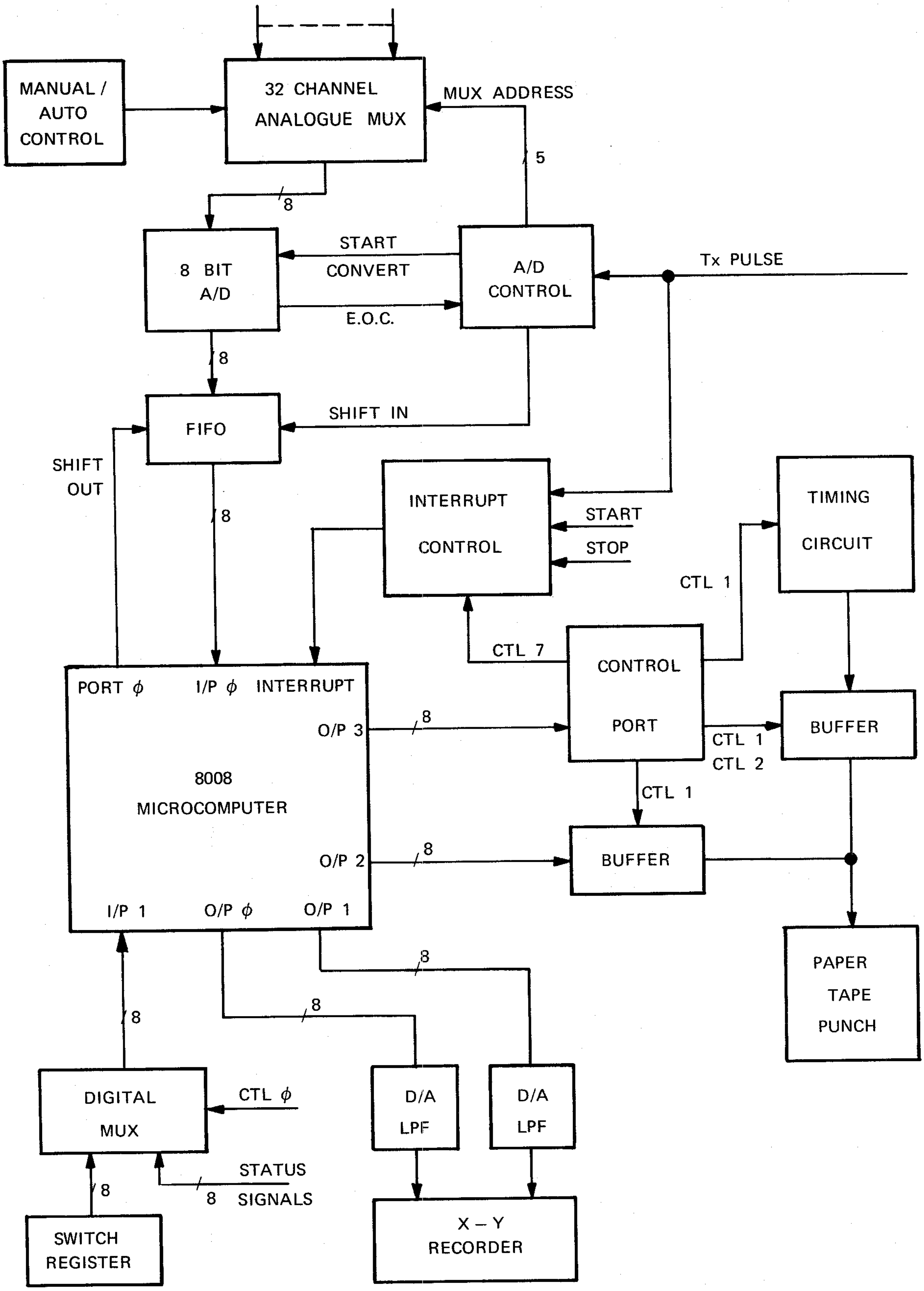


Figure 43. Block diagram of data acquisition unit

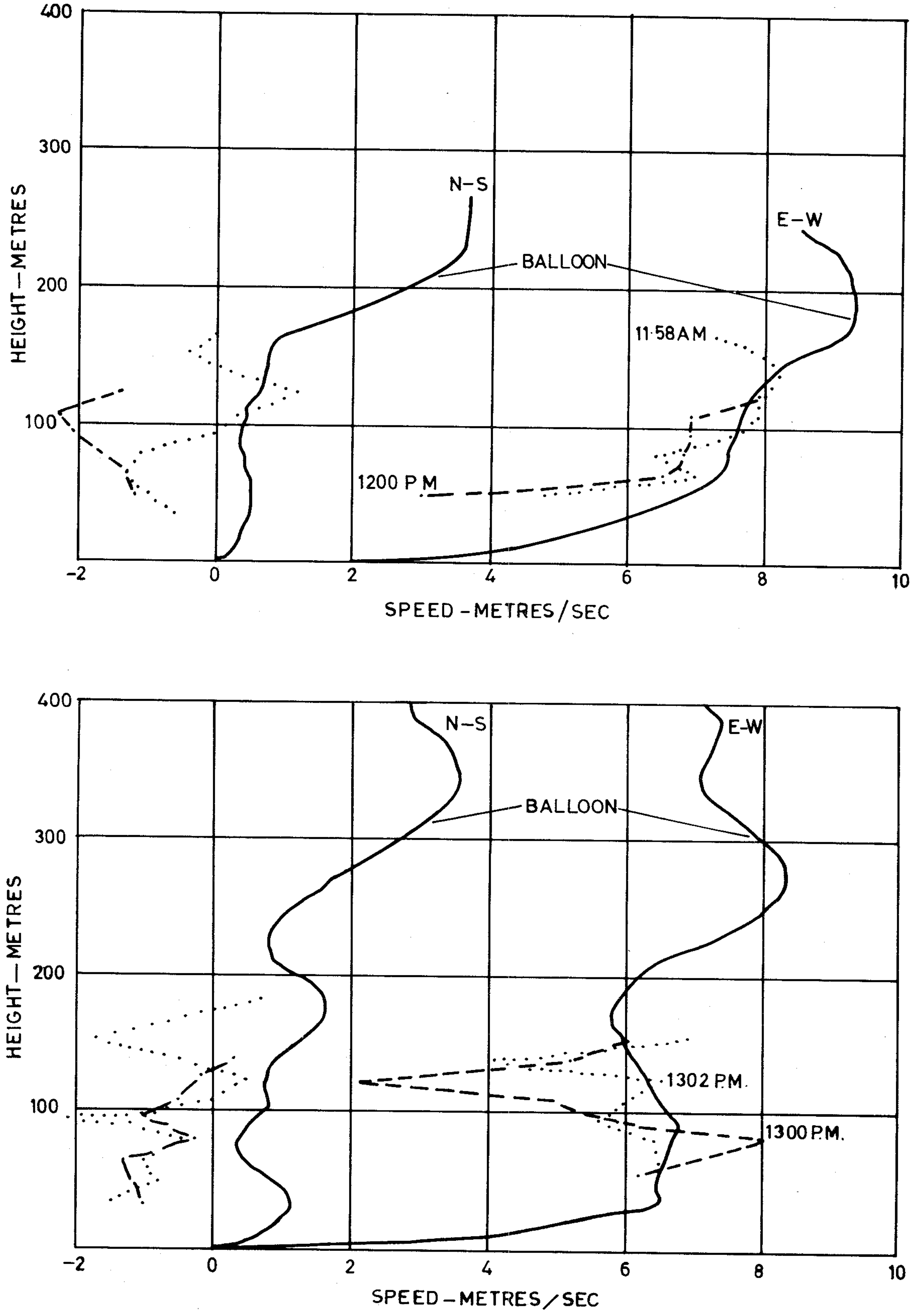
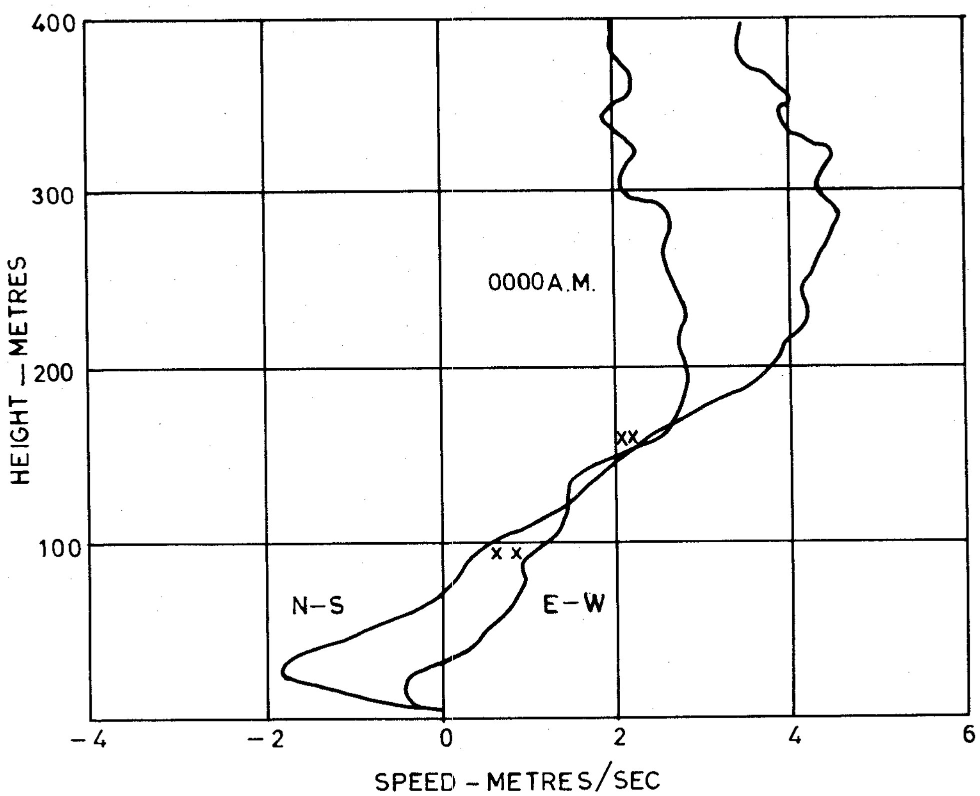


Figure 44. Measured wind profiles for 1200 and 1300 P.M. 31-7-78



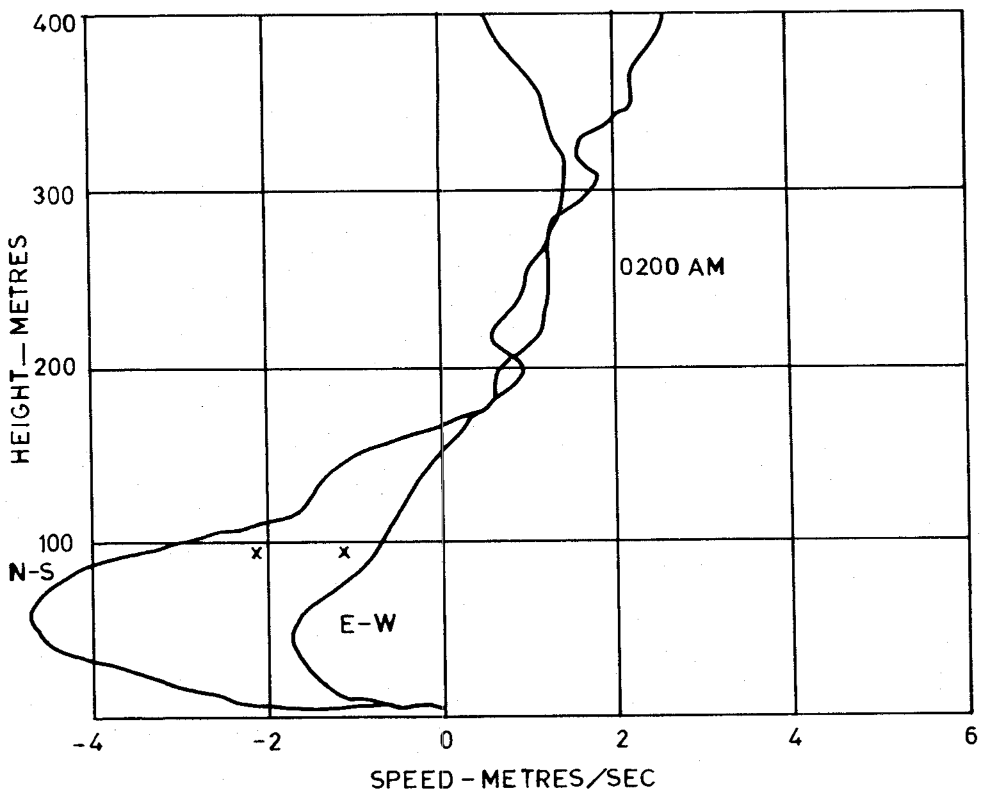


Figure 45(a). Measured wind profiles for 0000 and 0200 P.M. 1-8-78

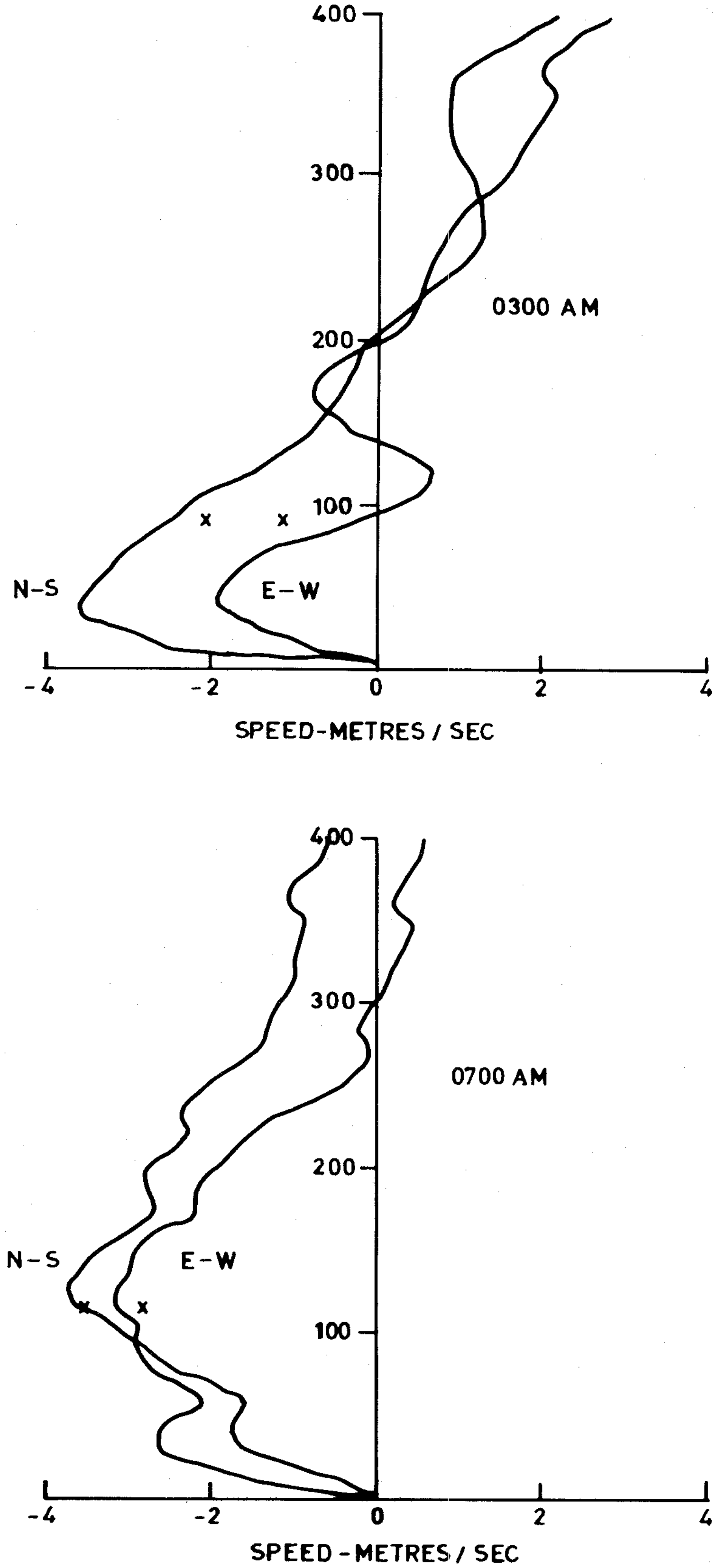


Figure 45(b). Measured wind profiles for 0300 and 0700 A.M. 1-8-78

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17 SUMMARY OR ABSTRACT:

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The DRCS acoustic sounding facility at Edinburgh Airfield has been developed to enable the simultaneous comparison of the ability of three acoustic sounding techniques to measure wind velocity profiles in the lower atmosphere. The three techniques are monostatic doppler, bistatic doppler and angle-of-arrival operation. The antenna configuration, electronic equipment and performance parameters are described.

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